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TABLE OF CONTENTS

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Edward C. Callahan

Captain Edward C. Callahan (SM'57), USN, was born in Dallas, Texas, on August 11, 1906. He received advanced instruction at the University of California, Extension Division, and Lincoln University, San Francisco, Calif. During his naval service he attended the Navy radar schools at Bowdoin College and Naval Research Laboratories from 1941 to 1942, the one-year course at the Industrial College of the Armed Forces, Washington, D. C., 1950–1951, and the twelve-week Advanced Management Program at the Harvard Business School in 1955.

From 1924–1941 he was employed as a civilian by the Fireman's Fund Insurance Company and the National Broadcasting Company, both in San Francisco, and in 1946 by the West Central Broadcasting Company, Peoria, Ill.

He was commissioned an ensign in the U. S. Naval Reserve in 1931 and became active in the Volunteer Communication Reserve, Twelfth District. Before and during World War II, Captain Callahan was assigned to active duty in the fields of communications, electronics, and training, and served on the U.S.S. *Minneapolis*. Subsequent assignments were: Task Force 65 (Air); Fleet Air Command, South Pacific; and Naval Air Technical Training Command.

After World War II he was assigned to the Bureau of Aeronautics; the Naval Air Development Center, Johnsville, Pa., as Director of the Aeronautical Electronic and Electrical Laboratory; and the U. S. Naval Training Device Center, Port Washington, N. Y., as Commanding Officer and Director.

Guest Editorial

EDWARD C. CALLAHAN

THIS issue is devoted to simulation in electronics. Its theme is synthetic simulation of the operational and maintenance situations created by modern military weapons and supporting systems. Simulation is achieved in great measure by electronic techniques. Generally, the papers presented treat the synthetic approaches in simulating systems characteristics induced by the vastness of space in modern flight.

The need for simulation by synthetic means is brought about by man's poor ability without external aids to visualize in full scope the operation of large and complex systems and weapons made possible by advanced technology. This need is well exemplified in the problem of matching the man to the machine in space flight. Simulation is used for studying the various psychological problems. Synthetic devices are needed as research tools to determine disorientation effects on human beings in various flight situations. Simulated operational situations are provided in order that a human being may experience the environment of particular weapon systems, and in a measure train himself for it before endangering costly equipment, and perhaps his life.

If considered as representative of the field, the eight papers published in this issue appear to indicate that the field of simulation is devoted largely to human factors problems. Simulators do find applications where human factors are not involved, such as determining the dynamic design features of a missile to fly a certain course or trajectory. But the vast majority of synthetic device and simulator applications come about because of the human engineering aspects. All of our arsenal of weapons would be inert and useless except for the functions of operations and maintenance performed by human beings. An essential element, therefore, in the effectiveness of modern weapons is properly-trained manpower. It is in the field of military training that synthetic devices and simulators find the greatest usefulness.

The design requirements for synthetic devices used in training embody significant differences from those governing weapons and support systems. Training devices and simulators directly relate to the man in the situation. They are aids to the instructors in imparting knowledge and to the trainees in learning. Since they serve in teaching-learning situations, their design characteristics must be based on approved educational and training principles. A continuing supporting program of human factors analysis in various training situations must be carried on to ensure adequate emphasis on the critical tasks. Vigilant surveillance over their utilization in classrooms and in the many operational training situations must be maintained to ensure adequate feedback of experience data for design improvement. Synthetic devices and simulators provided for training purposes are therefore clearly distinguished from military weapons and systems by their objectives to train operational and maintenance personnel.

Scanning the papers in this issue, we see that most of the authors are concerned with man's problems in comprehending the shape and surface features of the earth in order to be able to use various weapon systems effectively. The problems are many. To name only a representative few, consider the problems of navigation, especially celestial, and of radar surveillance of terrain features. Particularly troublesome are those involving the reactions that man experiences when he is detached from the earth in various types of flight vehicles. But the field of simulation is quite broad. Their application is not by any means limited to the flight situation. They are also used extensively to assist in solving human engineering and training problems in many situations where the man performs functions on terra firma.

The U. S. Naval Training Device Center is devoted entirely to synthetic devices and simulators, with strong emphasis on training. The IRE members on the Center's staff, particularly the PGMIL members, are thankful for the opportunity this issue is affording to disseminate information on this all-important program. Your guest editor acknowledges and is grateful for the aid and assistance rendered by the following in editing and preparing this issue: John Hickey, Chief Engineer, Sam Grodzinsky, Head, Simulator Branch, U. S. Naval Training Device Center, and Bill Cook, Sperry Gyroscope Company. We all sincerely hope that a worthwhile contribution has been made to the current outstanding series of guest-edited IRE TRANSACTIONS ON MILITARY ELECTRONICS.

Design Considerations for a Celestial Navigation Trainer*

M. D. BENNETT† AND N. B. MICKELSON†

Summary—**This paper gives a short history of the need for navigation training and tells what a navigator should know. It also tells how navigators were trained in the middle ages and of training devices used then as well as explaining the requirements of the modern celestial navigation trainer and how the 1A19 meets these requirements. It explains, in general engineering terms, the techniques used for simulation of motion and references and changes in references required for navigating.**

Introduction

THE term navigation in its present-day sense is used to describe a number of items. Generically, it encompasses Geonavigation and Celonavigation. Geonavigation includes the methods of locating the position of a ship or aircraft by earth landmarks or by geophysical characteristics. It may be subdivided into Piloting, which deals with bearings, buoys, lighthouses, soundings, radio beams, beacons and chart study; and into Dead Reckoning, which deals with methods of estimating the distance covered and the point reached in a given interval by means of compass observations, log readings, records of engine and/or air speed, and a few calculations. Celonavigation, or Celestial Navigation, may also be called Nautical Astronomy, or most correctly, Astronomical Navigation. Basically defined, it is the science of position finding away from all landmarks, when a ship is at sea, or more recently when in the flight of aircraft. This is done by sextant observations of the sun, moon, or certain planets or stars, with the notation of the exact time of each observation, and with the aid of certain almanacs and tables.

The modern navigator, practicing celestial navigation, makes use of the prominent heavenly bodies to determine his position. These are the sun, the moon, Venus, Mars, Jupiter, Saturn, and selected stars. It is vital that the navigator has a clear understanding of the locations and motions of these bodies in order to determine their positions in space and to orient himself accordingly. It appears, therefore, that one of the prime considerations of navigator training is a knowledge of astronomy and of the terms and vocabulary used. Without this basic tool it would be virtually impossible to train anyone in the navigational sciences. The second basic tool is a knowledge of earth magnetism (terrestrial magnetism) including an understanding of local conditions and the required corrections. Finally, in order to navigate successfully, a working knowledge of dead reckoning navigation is necessary. It becomes apparent from these statements that the training of a navigator can be a lengthy and tedious process, since once having absorbed the mass of knowledge indicated, the novice must be given sufficient practice covering numerous considerations and variations of parameters chosen from the above sciences.

Early navigators were trained by way of the "apprenticeship" method. This method proved to be a matter of chance rather than a method of selection, since the choice of an apprentice was usually left to the "master." Once chosen, there followed years of travel and training. The instruction was of an individual nature, and in many cases perpetuated the errors or specific ideas of the master under which one served. In addition, if most of an apprenticeship was spent in a particular geographical area, difficulty was later encountered in other global areas due to the inexact knowledge of the relationship of the different points on the earth's surface to the celestial sphere.

As the vessels of the newly developing countries began to sail greater and greater distances, and as seafaring became important to a nation's growth and well-being, schools were established for the training of navigators, or "mariners," as they were called. These schools were in later years followed by naval academies and specialized navigational schools. The advent of aircraft, World War II, and the development of certain types of missiles has accelerated the need for trained navigators and, therefore, the requirement for navigational training devices.

The concept of training devices is not new, as the history of the arts indicates. Early devices consisted of such individual items as the armillary sphere, the astrolabe, and the terrel. These items were used in the training of mariners, and pre-date the quadrant, sextant, and compass by many years. They were, of course, the subjects used in "individual" training programs and did little to cut down the actual time required to train a navigator. Our most modern training devices are designed for individual and/or group training in the fastest possible time, under simulated operating conditions. It is interesting to note, however, that there have been many approaches to the concept of group training. Among these were such ideas as hanging a group of sextants on a horizontal rod to permit group instruction, trailer trucks with sextants projecting through the roofs, planetariums, "chosen" star and/or fixed star projectors, collimated star devices, and many others. Figs. 1 and 2 illustrate a few of the more modern devices in use.

Considerations

Let us now consider the requirements of a modern celestial navigation trainer. For maximum utility, the device should provide for group (classroom) or individual training in celestial and dead reckoning navigation.

* Manuscript received by the PGMIL, April 15, 1959.
† The Reflectone Corp., Stamford, Conn.

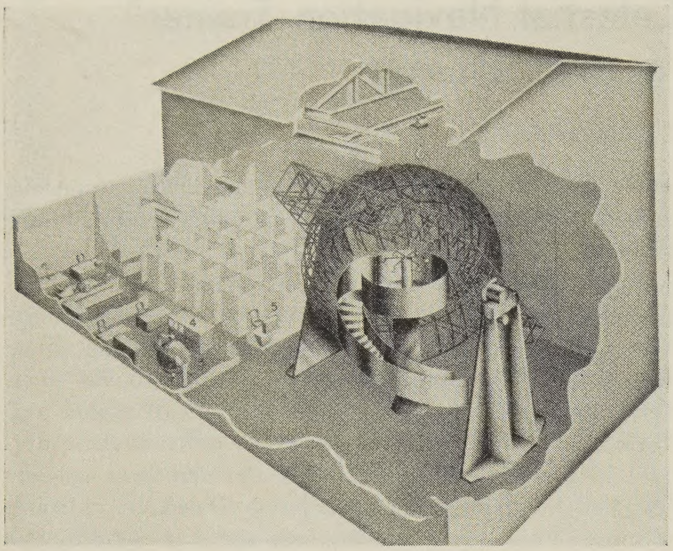


Fig. 1—Navigation Trainer, high speed, high latitude, Type D-2 (courtesy of U. S. Naval Training Device Center). 1) Celestial Dome, 2) Periscopic Sextants, 3) Automatic Dome Control and Flight Recorder, 4) Trainer Control and Flight Computer, and 5) Student positions.

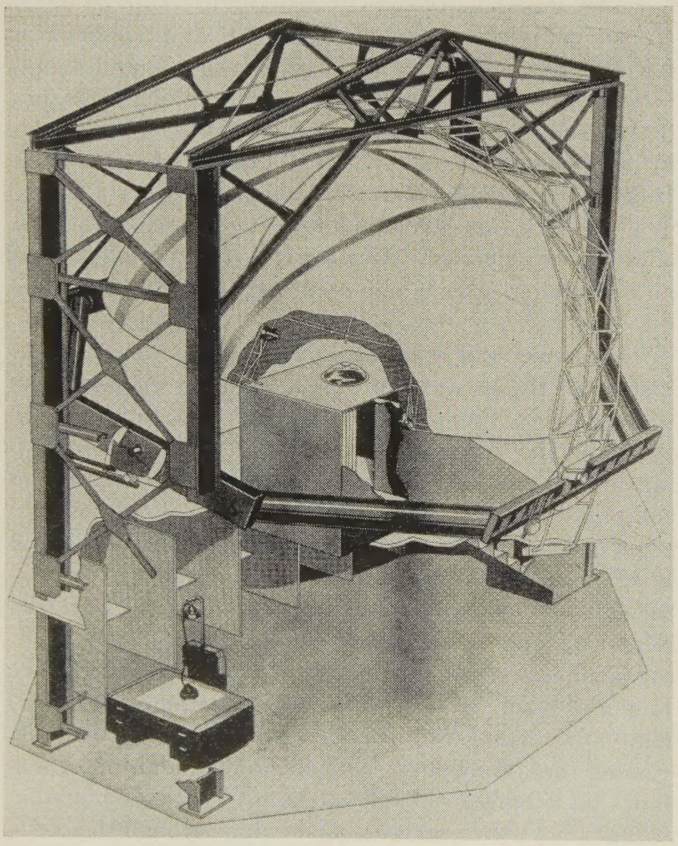


Fig. 2—Celestial Class Trainer, Device 1A18 (courtesy of U. S. Naval Training Device Center).

It should be capable of covering the Northern and Southern hemispheres, including the Polar regions. In effect, the trainer should simulate the navigational conditions presented by modern high-speed aircraft, where the navigator is required to derive flight data from celestial observations and dead reckoning instruments anywhere on earth.

The trainer should be designed to teach the use of the operational sextant and sky compass in deriving sun and star information. Dead reckoning information, such as barometric altitude, radar altitude, heading, free air temperature, air speed, and time should be displayed to the students so that an accurate log and plot of the flight path can be kept. Additional data such as wind parameters and ground speed may be made available through the use of a driftmeter, or similar ancillary devices.

The dead reckoning instruments should be so located that they may be monitored continuously by a group of students. Readings on the sextant, sky compass, and driftmeter occupy only a small portion of the individual navigator's time and may be accomplished by one student at a time during the course of a problem.

Astro data should show correctly-positioned stars and/or the sun. Accurate readings of these displays should be possible by using the periscopic sextant. A separate display simulating polarized sky light should be provided, correctly oriented as seen at the zenith, and read by means of the sky compass.

A graphic ground track recorder should permit the instructor to continuously monitor the simulated flight path, which may then be compared with the logs of the individual students. The recorder display may be either Mercator or Polar plot, depending upon the region over which the "flight" takes place.

The Training Device

One device designed to meet the summarized conditions outlined, is the Celestial Navigation Trainer, Device 1A19 (Fig. 3), produced by the Reflectone Corporation, Stamford, Conn., for the U. S. Naval Training Device Center, Port Washington, L. I., N. Y. A block diagram of the device is given in Fig. 4.

Let us now consider, in the light of what is required of the device, how this particular trainer accomplishes its mission.

Fundamentally, the trainer is an interrogation-response device. That is, the Instructor's Console acts as the focal point from which all navigational and astral data emanate. The results of the insertion of these data are presented to the students as a series of instrument and indicator readings, and as star and sun positions. The students must solve the problems of dead reckoning navigation by using conventional means. Solution of navigational problems by celestial means is accomplished by using an operational periscopic sextant, which shoots simulated stars whose altitude and azimuth are computed and fed into a star drive capable of correctly positioning the star image with respect to the position and heading of the simulated aircraft.

The Instructor's Console

In order to control and vary the required parameters, the design of the Instructor's Console (Figs. 4 and 5)

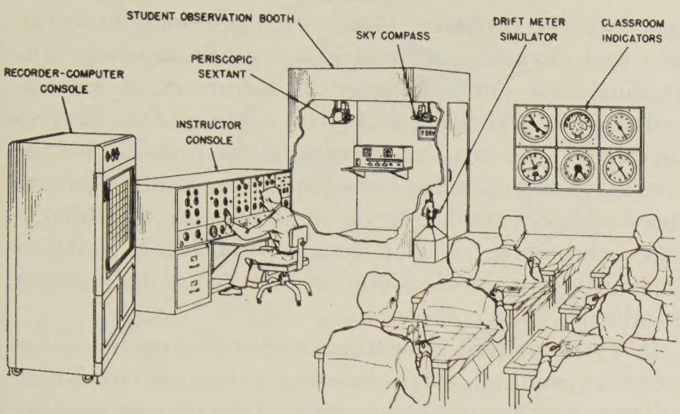


Fig. 3—Celestial Navigation Trainer, Device 1A19, set up for classroom use.

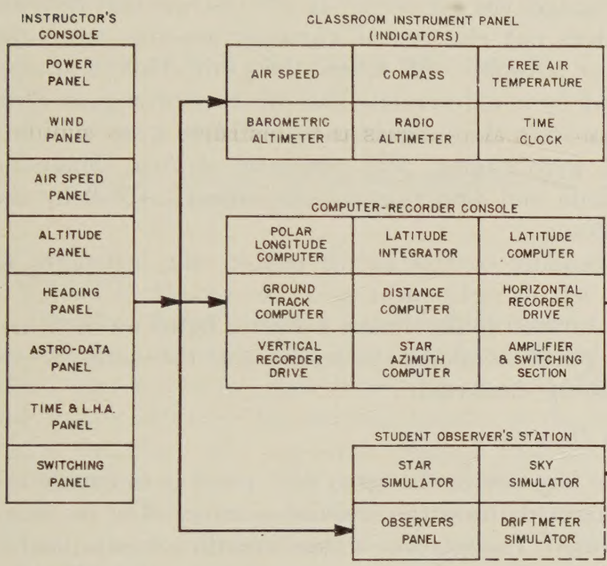


Fig. 4—Schematic block diagram of Celestial Navigation Trainer, Device 1A19.

provides for the following control panels:

Wind Panel	Heading Panel
Air Speed Panel	Astro Data Panel
Altitude Panel	Time Panel.

In addition, means for turning the equipment on and off have been provided on a Power Control Panel, and various switching functions have been provided on a Switching Panel.

The characteristics of each of these panels can now be considered:

Wind Panel

The wind panel provides a wind speed dial calibrated in knots, a speed change dial calibrated in knots per hour, a wind direction dial calibrated in degrees, and a direction change dial calibrated in degrees per hour. With these dials, the instructor can set up the wind parameters at the beginning of a problem and vary them as required during the course of the problem. The change dials are incorporated to simulate flying across pressure patterns.

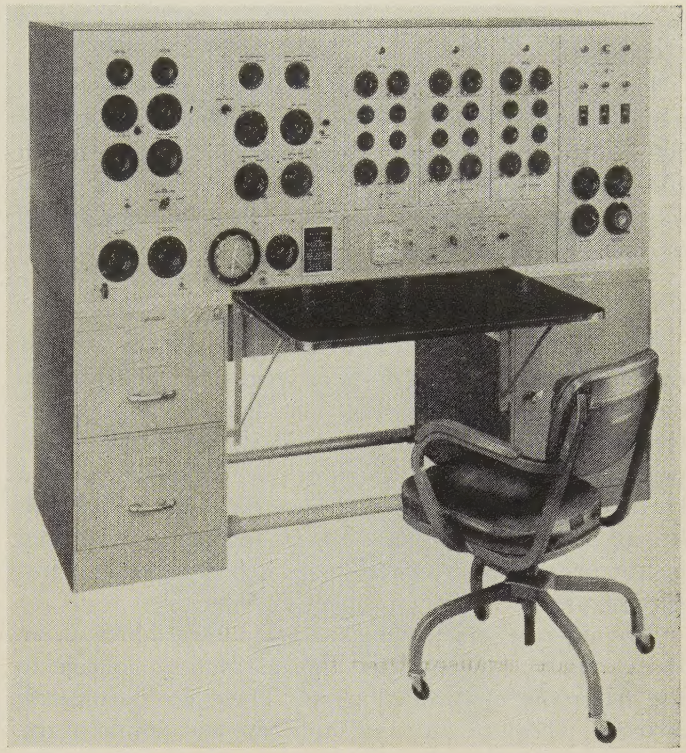


Fig. 5—View at front panels of Instructor's Console. All input parameters are adjusted at these panels.

The voltage used to represent wind speed is derived from a variable autotransformer connected across the secondary of a voltage reference transformer. This wind speed voltage is then applied to a resolver. The North-South and East-West wind speed components from this resolver are summed with the East-West and North-South true air speed components (developed by the Air Speed and Heading Panels) to produce the correct ground speed components.

Air Speed Panel

The air speed panel contains the computer air speed control and a dial for setting the student's air speed indicator, both calibrated in knots. It also contains a computer true air speed (TAS) range selector switch and a selector switch to indicate to the students whether indicated air speed (IAS) or true air speed is being transmitted to the air speed indicator. The function of this panel is to permit the instructor to insert the air speed parameters required for the problem.

As in the wind panel, a variable autotransformer connected across a tapped secondary winding of the same voltage reference transformer used for wind speed is controlled by the computer true air speed dial, and transmits true air speed to a true heading resolver whose output will be the North-South and East-West components of true air speed. These N-S and E-W components of true air speed are then summed with the corresponding components of wind speed to develop the correct ground speed components.

The trainer can be made to operate in either of two conditions. In the first condition, the speed range is 0

to 300 knots. In the second condition, the range is 0 to 1500 knots.

The voltage across the autotransformer winding represents a continuously variable speed range up to 100 or 500 knots. The level of this voltage may be shifted in 100- or 500-knot steps by the maximum true air speed range switch to provide the total speed ranges of 300 or 1500 knots, as required.

Altitude Panel

The altitude panel contains input dials for free air temperature and ground air temperature calibrated in degrees centigrade, absolute altitude dials calibrated in feet, a pressure rate of change dial calibrated in feet per hour, true altitude dials calibrated in feet, and a barometric pressure dial and a vertical speed dial calibrated in feet per minute. These controls are to be used by the instructor to establish the altitude and temperature parameters for the problem.

The altitude system functions as follows. Three quantities are transmitted from the instructor's console to the classroom instrument panel. These are barometric altitude, absolute altitude, and free air temperature. A rate-of-climb-or-dive integrator, whose rate is controlled and indicated by a dial, develops a true altitude function. This function positions the true altitude dials and the inputs of two differentials. The barometric pressure dial positions the second input of the first differential. The output of this differential is, therefore, the true altitude plus barometric pressure error. This quantity is transmitted to the barometric altimeter on the classroom instrument panel. When the barometric pressure correction is inserted at this latter instrument, it will read the true altitude.

The other input of the second differential is derived from an integrator. The output of this integrator is controlled by the setting of the pressure pattern rate dial, and represents the change in true altitude caused by flying a plane of constant pressure. The output of this second differential represents, therefore, the sum of the initial setting of true altitude plus the change due to flying through a pressure pattern. This output positions the absolute altitude system. The absolute altitude is transmitted to the absolute altimeter on the classroom instrument panel. The absolute altitude function also positions the input of a third differential. The other input of this differential is positioned from the ground air temperature dial. The output of this differential is free air temperature and decreases with absolute altitude. A mechanical stop is inserted between the absolute altitude system and the air temperature differential to cut out the temperature lapse rate at an absolute altitude of about 27,000 feet.

Heading Panel

The heading panel permits the instructor to choose magnetic system or gyro system parameters for insertion into the problem. The system provides for variation and deviation corrections, compass heading, true heading dials, and gyro error, all calibrated in degrees; and a gyro precession rate dial calibrated in degrees per hour. True heading is set into the problem by the instructor and operates a resolver to develop the ground speed components. Variation and deviation are added to true heading to develop magnetic heading which is transmitted to the classroom instrument panel where it is indicated on a compass dial.

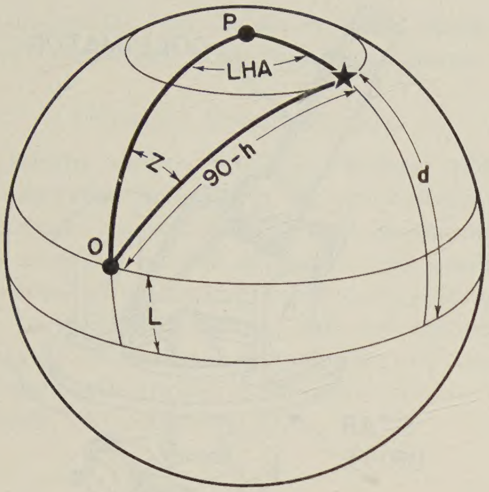
In gyro compass operation, variation and deviation are set as required. A true heading is then inserted which will position the air speed resolver. The compass heading is then the sum of true heading and gyro error. When a precession rate is introduced, this rate is integrated and changes the gyro error. It also changes true heading but does not change the compass heading, since the pilot or autopilot will follow the gyro. This is accomplished by a differential. The presence of a gyro error dial permits the instructor to simulate gyro malfunctions, gyro caging, and magnetic slaving. Magnetic variation and deviation may be altered at will by the instructor.

A heading control switch enables the instructor to make left or right turns at 3° per second. A switch is also provided to illuminate indicator lights on the classroom panel to inform the students of the compass system being simulated.

Astro Data Panel

The function of the astro data panel is to enable the instructor to insert the celestial coordinates of the stars to be used. The relation of these coordinates is indicated on Fig. 6. The sine and cosine of the star declination angle are inserted separately, using switches and dials on induction-type voltage dividers. A value of the sidereal hour angle (SHA) is inserted by dial-controlled synchros. The trainer being considered in this report provides for a selection of three stars for use in any one problem. However, the unitized construction of the actual functional device provides for the addition of any practical number of stars. In the system considered, the altitude and azimuth of only one star, selected by the student, is derived at any one time. The celestial coordinates of the stars to be observed are inserted by the instructor as previously described. The instructor also checks the setting of a clock drive which indicates civil time and inserts into the system the correct value of sidereal time. Once the values described are inserted, the instructor is not required to do any computation of quantities such as local hour angle, and so forth.

A star selection system of relays presents the desired star to the student. A pilot light on the astro data panel informs the instructor of the star being used. It is possible to change one star to simulate the sun in appearance.



sin h = sin d sin L + cos d cos L cos LHA

cos h sin Z = cos d sin LHA

cos Z cos L cos h = sin h sin L

Fig. 6—Spherical Triangle defining star azimuth relative to observer and pole.

Time Panel

The time panel contains a twelve-hour master clock to which all other clocks in the system are slaved. This clock may be set to either local time or to GMT, and will run in civil time. By means of gearing of the correct ratio, the clock will introduce sidereal time into the computation of LHA. The panel also contains a digital clock to indicate elapsed time of the flight problem. A computer is provided which adds present time to the quantity SHA+Longitude to develop LHA and the quantities cos d cos t and cos d sin t. In this particular trainer, this section of the computer has been incorporated in the time panel assembly for reasons of manufacturing economy, and not because of any technical design consideration.

Power Panel

The power panel provides the proper voltages required to operate the equipment, as well as electrical protection by means of circuit breakers.

Associated Switching Panel

Since one of the design considerations is the possible use of ancillary equipment, a switching panel has been provided. In addition to fuses, switches, and relays required for properly controlling the driftmeter illumination (simulating day and night conditions), caging and uncaging the driftmeter gyro, and controlling the intensity of the sun image in the student observer's booth, it also provides a means by which the instructor may mark the recorder chart and control polar and sub-polar trainer operation.

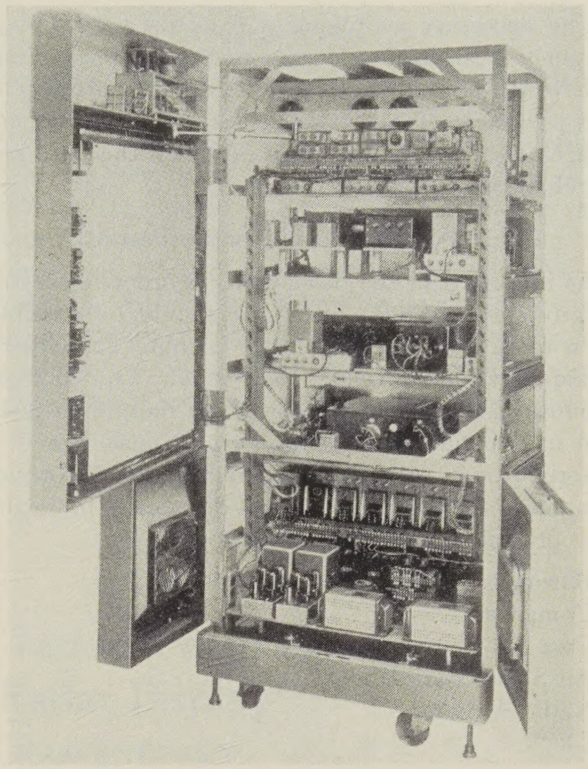


Fig. 7—View at inside of Computer-Recorder Console. Ground track graphic recorder is mounted on a hinged door, shown in swung-out position. White panel on recorder door diffuses light for recording chart which is visible when door is closed.

The Computer-Recorder Console

The computer-recorder console (Fig. 7), in addition to containing the amplifier and the recorder section, provides the following computers:

Polar Computer
Latitude Computer
Sin h Computer
Ground Track Computer
Distance Computer
Horizontal Recorder Drive (Longitude Computer)
Vertical Recorder Drive
Star Azimuth Computer
Latitude Sub-Polar
Longitude Sub-Polar.

Since good design requires that problems be conducted at any point on the earth, the recorder is provided with four interchangeable charts. The charts are permanent (made of glass), and equipped with a lightly-etched recording surface. The record is of a type that may easily be erased. Such charts avoid complications due to warping or stretching (as with paper charts). The three sub-polar charts are Mercator charts. The polar chart is a grid chart with the pole at the center. In addition to the grid, the principal meridians and parallels are shown for reference purposes. This type of presentation requires consideration of methods of correcting for Mercator projections, in one case, and for polar-grids, in another.

The necessary switching and initial positioning for uniquely locating the chart in use is held to a minimum. It is worth noting, that by these design considerations, it is possible to fly across the equator as well as across either pole. Two sets of dials establish the base line of the chart in use.

Classroom Instrument Panel

As indicated in the discussion, in order for a trainer to provide maximum utility, it should be possible to train more than one student at a time. The classroom instrument panel provides the basic data for such group training, which is then followed by individual instruction in celestial observation, as previously noted. The classroom instrument panel provides the following instruments enlarged to 18-inch diameters to facilitate ease of reading by the student body:

Barometric Altimeter
Compass
Free Air Temperature Indicator
Air Speed Indicator
Radio Altimeter
Clock.

All of these instruments are actuated by synchros positioned by their respective inputs from the Instructor's Console. The air speed indicator has indicator lights which can be actuated by the instructor to inform the students whether the instrument is reading true air speed or indicated air speed.

The Compass is also provided with indicator lights to show its condition of operation (magnetic, free gyro, slaved gyro).

The Barometric Altimeter provides an adjustment to permit the students to correct the instrument for the barometric pressure inserted by the instructor.

The air speed indicator simulates the conventional maximum allowable air speed indicator. The maximum pointer and the Mach scale are inoperative, however, as they are not necessary in this type of trainer.

The design of the dial faces has considered the parallax problem.

Student Observer's Station

In this trainer, the student observer's station is a booth-type enclosure atop which is mounted the star drive assembly. The interior provides a wall desk for student use, and a step ladder for aid when necessary to secure proper eye level height for the periscopic sextant. In addition to the periscopic sextant, provision is made for use of a sky compass to take azimuth bearings on a simulated sky. The observer's station also provides a panel containing the following items:

Compass with indicator lamps
Clock slaved to clock on instructor's console
Switches for selecting stars to be used in a problem

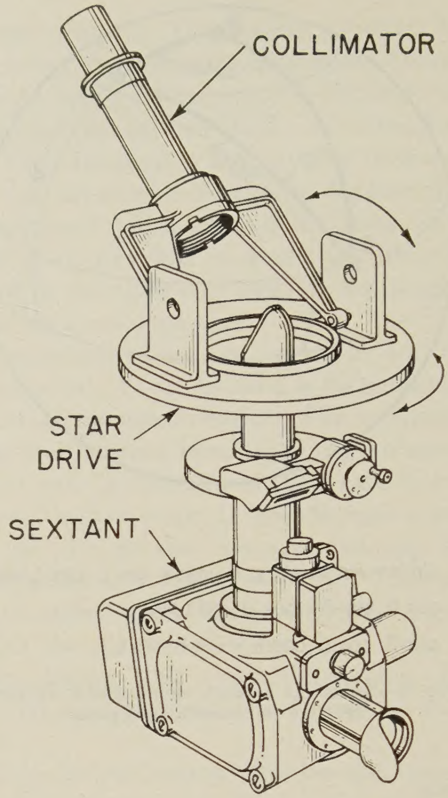


Fig. 8—Schematic diagram of arrangement of Star Collimator, Drive and Periscopic Sextant.

Adjustable red lighting over the desk and instrument panel.

In this particular training device, two possible methods were considered to simulate the celestial bodies.

Method 1. The star/sun image was to be created by reflecting a small light source from a polished steel ball.

Method 2. The star/sun image was to be created by a small collimated light source mounted on a yoke (Fig. 8).

The second method appeared to be the most practical in terms of production costs, accuracy, and realism, and was thus chosen and developed. It made possible the use of an operational periscopic sextant, without modification, and permitted the use of a collimator. The star simulator drive unit was designed to reproduce the coordinates of the stars selected by the instructor for use in the problem. The altitude drive revolves 85° in an arc in a vertical plane about the horizontal axis of the optical center of the periscopic sextant, while the azimuth drive revolves a full 360° in a horizontal plane about the vertical axis of the optical center of the sextant. As in the operational situation, it is necessary for the student to level the sextant correctly while taking a sight on a star.

Provisions have also been made for the use of a sky compass which, for reasons of simplicity, is separate from the periscopic sextant mount. A skylight polarizer

is mounted directly over the sky compass mount and is positioned in azimuth from the astrocomputer.

Over-all Considerations

The training device employs wherever possible a magnetic amplifier to minimize the use of electron tubes. All mechanical or electromechanical computer assemblies are mounted on pull-out racks, and similarly, all amplifiers containing vacuum tubes are on sliding chassis in order to facilitate checking and maintenance, thus rendering all critical components instantly accessible. Finally, the entire trainer is energized from a commercial 60-cycle, 110-volt power line.

Conclusion

The design considerations and solutions provided by the Celestial Navigation Trainer, Device 1A19, indicate that it is possible to provide for rapid training of navigational personnel under any and all geographical conditions. The device is in no way dependent upon climate, atmospheric conditions, or other limiting local conditions. It is based upon operational equipment and provides for optimal training of groups or individuals. Its accuracy is well within the limits required for practical navigation. Finally, it requires no complex operating instructions or highly-complicated charts for operation.

Synthetic Representation of Terrain Features on a Simulated Airborne Radar Display*

J. T. SLATTERY† and M. KAMENETSKY†

Summary—**This paper traces the development of the various techniques used to generate synthetic land mass or terrain radar signals for radar training devices. The survey begins with a description and assessment of the Ultrasonic System and concludes with a discussion of the more flexible Two-Transparency System now under development by the Navy.**

Increasing importance of modern radar systems has resulted in a need for improved methods of training radar operators in recognition and interpretation of land-mass radar signals on radar indicators.

The first successful attempt to solve the problem of synthetic reproduction of terrain features on an airborne-type radar display, commonly referred to as land-mass simulation, was the U. S. Naval Training Device Center's Device 15Z1. This device, known as the Ultrasonic Trainer, provided ground training in precision navigation and bombing flights. As a first solution to the basic problem, it was natural that the system would be a direct analogy to the actual operational radar system. The analogy was established by replacing the radar RF components (magnetron, radar antenna, RF lines) with an ultrasonic system. Basically, this trainer consists of a piezoelectric crystal oscillator suspended from a movable cross-carriage in a tank of water (see Fig. 1). The crystal then "flies" over a submerged terrain map of an area of anticipated real flight navigation or bombing missions. The whole system is synchronized electrically to translate and present to the radar set the same situation, at the same speed, as an actual flight over the same territory. As the trainee "flies" the ultrasonic course, he sees a constantly varying presentation that looks as it would in the air. Effects of changing altitude and the direction and magnitude of azimuth motion are identically simulated. Noise interference, spurious range marks, and ghost sweeps show up as they do in the actual system. Thus, by means of this classroom equipment, a radar operator can be taught to operate controls, interpret scope displays, solve simulated airborne radar problems, and to be briefed. Fig. 2 is an artist's representation of the equipment components. Fig. 2(a) shows the map, which is a three-dimensional model or bas-relief map, submerged in the tank of water. The airplane in this figure represents the crystal oscillator. Fig. 2(b), the echo-simulator, represents the group of electronic chassis needed to energize the crystal, amplify the received echo, delay the trigger, synchronize the azimuth rotation of the crystal and the tilt and nod of the reflector with the radar antenna, and provide the required power supplies. Fig. 2(c) shows the radar display.

The development of Device 15Z1 was accelerated due to a natural phenomenon of the ratio of the velocity of light to the velocity of sound in water. With water at 20°C, or 68°F, the ratio of the velocity of sound in water to the velocity of light is 1:200,000. This ratio provided a convenient scale for terrain models and was so utilized. The 15Z1 ultrasonic transducer is a quartz crystal, con-

* Manuscript received by the PGMIL, April 15, 1959.

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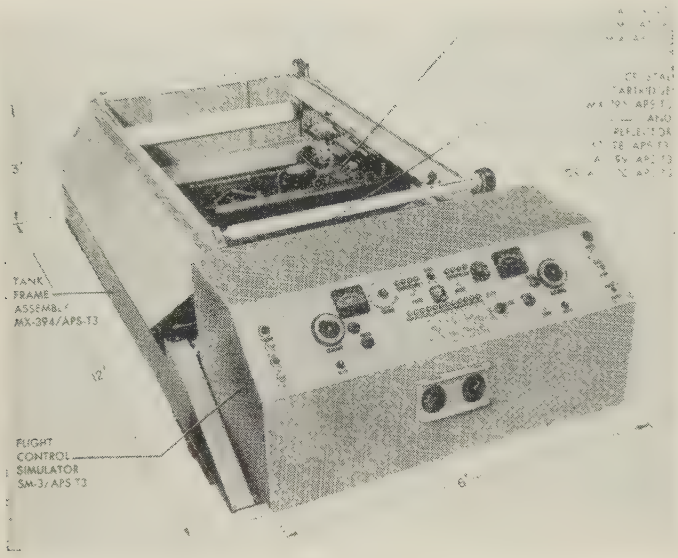
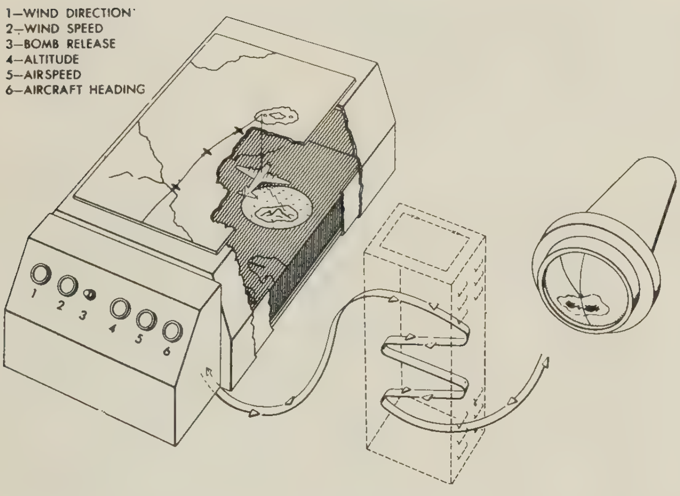


Fig. 1—Device 15Z1.



(a) (b) (c)

Fig. 2—Device 15Z1; (a) flight simulator, (b) echo simulator, (c) radar.

tained in a crystal head, and carries a reflector to simulate the beam shape of the radar set in use. The beam is generated by an electronic crystal driver unit, triggered by the radar set. The energy has a frequency of 15 mc with a pulse length of 1 μsec. When reflected from the map, the echo behaves in a manner very similar to that of the radar beam. It is received by the same crystal vibrator, amplified electronically, and converted to the intermediate frequency of the radar set. From this point on, the radar set corresponds exactly as it would if it were in an aircraft connected to its own antenna, and the display elements provide a presentation similar to that observed in actual flight over the area. The ultasonic map is designed of plastic in bas-relief. If required by field activities which do not have cartographic facilities available, the map can be built up and mounted on glass. All water areas are represented by clear surfaces which reflect the ultrasonic wave in a mirror-like manner with little scattering. Land forms are scaled in relief and are presented by a roughened surface which scatters the radiation as ordinary solid terrain scatters radar energy. More prominent targets are presented by carborundum cemented to the surface; heavily industrialized areas are coarse grained, while residential areas are relatively finer grained. The simulation of aircraft motion with respect to a fixed point on the ultrasonic map is accomplished by supporting the crystal vibrator and reflector over the map on an X-axis cross-carriage or trolley, which, in turn, is supported and moved along the tank by a miniature overhead-type Y-axis crane called the bridge. True airspeed, heading, wind speed, and direction are set into the control panel and are converted into rectangular coordinates. The combined coordinates are transmitted mechanically to the crane and carriage and converted into trolley motion in terms of aircraft course and ground speed. Thus airspeed, aircraft heading, and altitude are under control of the trainee, allowing him to "fly" the aircraft during the course of a problem. Servo systems provide antenna nod and tilt and azimuth motion characteristic of the actual radar system.

Unfortunately, the very thing that accelerated the development of Device 15Z1 provided a limitation to its continued use. The fixed velocity ratio of sound in water to that of light restricted map scales to 200,000:1. The net result was that a 6×4 foot map permitted a "flight" over an area approximately 190×120 nautical miles. Training problems involving greater distances than this have to be interrupted while the map is changed. This poses a severe limitation when classroom space is small or when training involves simulated flight of modern, high-speed, long-range aircraft. Other limiting factors to the extended use of this device are maintenance problems associated with the use of water, such as bulk, the critical requirement for the close control of water temperature, and the undesirable effects of dirt and other impurities in the water. The speed of the simulated aircraft and the mechanical scan rate of the simulated antenna are limited because high speeds or high scan rates create water disturbances which affect the ultrasonic returns. In addition, the degree to which the crystal oscillator can be miniaturized results in a simulated radar signal which is characteristic of an actual radar with an enormous antenna.

While this device still continues in widespread use, the Navy has eliminated some of the above noted limitations with a change in technique. The next major step in the development of land-mass simulation was another product of the U. S. Naval Training Device Center, known as Device 15Z4.

This device, illustrated in Fig. 3, employs light-reflectance techniques and a three-dimensional terrain model to reproduce realistic terrain features on a radar indicator. The basic components of the device, as shown in detail in Fig. 4, are a flying-spot scanner which supplies the source of illumination, the terrain model, an optical system which focuses the light on the terrain

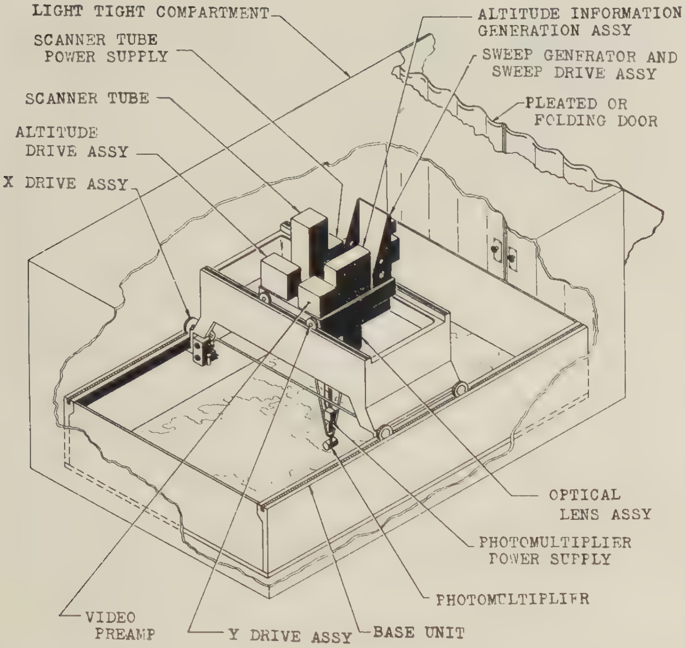


Fig. 3.

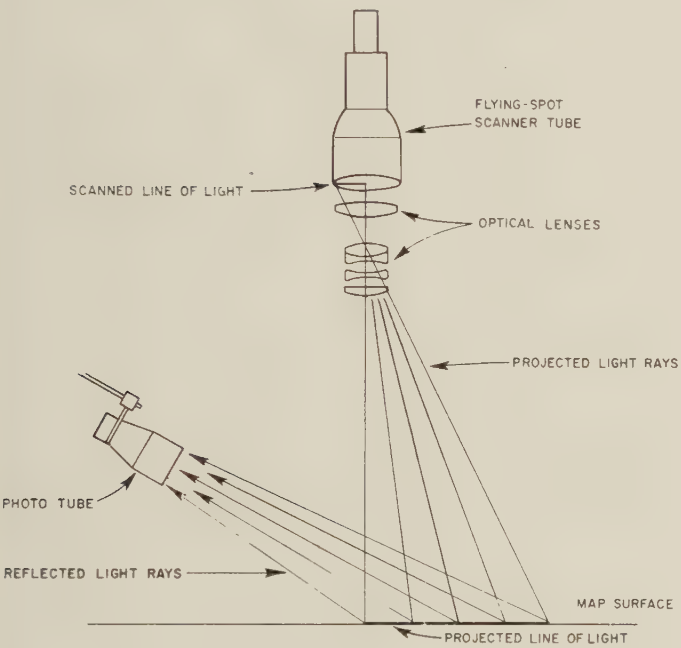


Fig. 4.

model, a photomultiplier tube which receives the reflected light energy from the terrain model, a computer and servo system which simulate the motion of the aircraft, and a radar system which processes the terrain information and presents it on the radar indicator. The 15Z4 system differs from the 15Z1 and the actual operational systems in that the source of the radiated energy and the receiving element are physically separated. However, suitable sweep and timing circuitry permit the 15Z4 system to obtain the same results.

The flying-spot scanner and optical system cause a high-intensity spot of light to sweep across the face of the map. The sweep rate is a function of the map scale

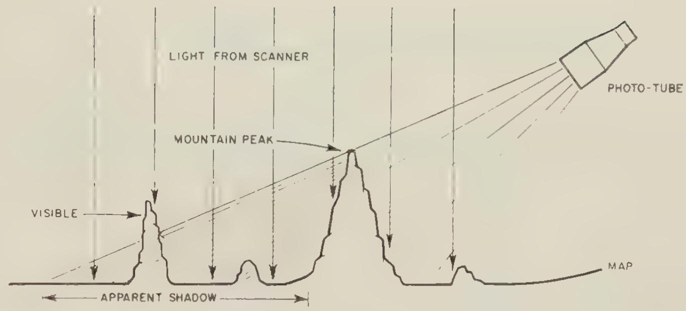


Fig. 5.

being used. Fig. 5 illustrates the manner by which terrain shadows are produced to give the effect of terrain elevation. The phototube receives light reflected from an unobstructed terrain in its field of view. Thus, the mountain peaks shown in the figure cause an apparent shadow even though this area is actually illuminated by the scanner. The upper part of the mountain at the left of the model is visible, but its base will be in shadow as is the small peak in the center. Correct radar reflectivity is achieved by painting the terrain the proper shade of gray. The reflected light reaching the phototube is thus modulated and results in a radar-indicator display which varies in intensity with the terrain reflectivity as in an actual airborne radar. The effect of altitude is achieved by varying the height of the phototube above the terrain model. Each altitude position results in a different shadow pattern since some areas in shadow at one altitude become visible at another, and vice-versa.

Aircraft motion is simulated by moving the entire 15Z4 optical system, phototube, and flying spot scanner along two coordinate axes by means of a carriage and gantry. The system moves in response to signals from the computer-servo course generator, which generates the parameters of the problem.

In an actual radar system, target echoes are received at a time corresponding to the line-of-sight distance to the target or the slant range. In the simulator, however, targets inherently appear at a distance corresponding to their distance along the surface of the map or ground range from the position of the simulated aircraft. To overcome this basic ambiguity, a hyperbolic time delay is introduced into the flying-spot scanner deflection current. Thus the spot of light on the model is retarded with respect to the sweep on the radar indicator so that it reaches a particular target at a time corresponding to the slant range from the simulated aircraft (represented by the phototube) instead of the ground range. To illustrate how this is achieved, reference is made to Fig. 6.

With units in feet or miles:

Let R = ground range from aircraft to target measured along the surfaces of the model,

Let r = slant range or the line-of-sight distance from aircraft to target,

Let h = aircraft altitude above ground,

Let c = velocity of radar propagation.

In the actual radar system, the target appears at a time after the main bang corresponding to

$$t = 2r/c.$$

However, the flying-spot scanner deflection current (I_d) is directly proportional to ground range R, or

$$I_d = KR$$

where K is a scale factor in milliamperes per mile.

Using the Pythagorean theorem to solve for ground range,

$$R = \sqrt{r^2 - h^2}$$

which may be recognized as being in the general form of a hyperbola.

Substituting this value of R in the expression for the deflection current,

$$I_d = K\sqrt{r^2 - h^2}$$

which may be converted to slant-range timing by utilizing the equation for the time-delay of an actual radar signal which is

$$t = \frac{2r}{c} \quad \text{or} \quad r = \frac{tc}{2}.$$

Thus

$$I_d = K\sqrt{\left(\frac{tc}{2}\right)^2 - h^2} = \frac{Kc}{2}\sqrt{t^2 - \left(\frac{2h}{c}\right)^2}.$$

Using $t_h = 2h/c$ = time delay due to the aircraft altitude,

$$I_d = \frac{Kc}{2}\sqrt{t^2 - t_h^2}.$$

This shows that the scanner deflection current is directly proportional to the slant range time (or distance) to the target for a given altitude.

If, over the range of interest, various values of h are assumed and R vs r or I_d vs t is plotted, a family of hyperbolic curves or sweeps results. The hyperbolic sweeps, which approach a linear sawtooth curve asymptotically, can only be linear at zero altitude. (See Fig. 7.)

An essential element of the 15Z4 land-mass simulator is the terrain model which provides the radar reflectivity information of the terrain. A typical model is made of a noninflammable plastic which is cast from a master mold. The specific areas of interest are hand-painted on the model with a shade of gray based on a radar reflectivity scale. Cities and other built-up areas will generally be painted a brighter shade to produce a greater intensity return than the surrounding wooded areas. Some targets yield strong returns when received from a given azimuth angle, but little or no return when received from some other angle. This directivity effect is achieved by use of small metal or glass inserts on appropriate sides of the target, which reflect light in only one direction.

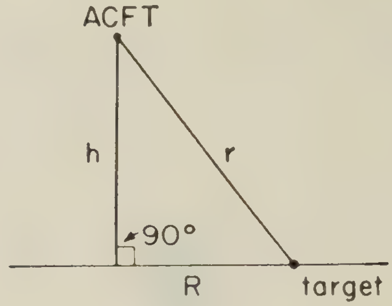


Fig. 6.

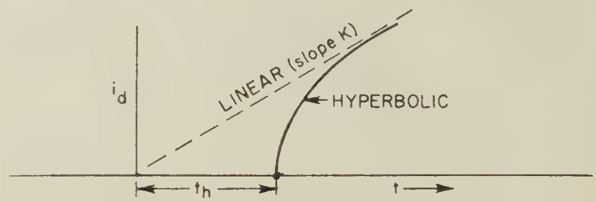


Fig. 7.

Coarse or irregular terrain returns are achieved by use of a gritty finish which has a scattering effect on the incident light. Water-land contrast is achieved by painting water areas a glossy black.

The 15Z4 land-mass simulator provides flexibility in the use of various map scales. The present system is designed for use with models using scales of 100,000 to 1; 250,000 to 1; and 500,000 to 1. Models made to larger map scales are not used because of the limitations imposed by the physical size of the target inserts. Advanced-design flying-spot scanners and improved optical systems have enabled this simulator to produce high-resolution radar displays.

However, the device is not without certain limitations. One of the most important of these limitations is the fact that at present it does not lend itself to low-altitude operation. The present minimum altitude is about 1000 feet above ground level. This limitation stems from the finite size of the photomultiplier tube which prevents it from being maneuvered below the terrain peaks of the model. Thus the tube "sees" terrain which should normally be in shadow. It is not possible at present to use the device to produce a terrain clearance or obstacle-avoidance radar display since the phototube would have to be physically maneuvered below the mountain peaks so as to simulate an aircraft flight through valleys formed by the mountains.

Another objection to the 15Z4 system is its size and weight. The optical system, including the scanner, power supplies, and phototube, is supported by a heavy gantry and carriage which are positioned over a massive map bed. This results in problems of space allocation, especially in mobile versions of the simulator.

The development of systems of land-mass simulation has been based on attempts to permit simulated flight at lower altitudes, increased map area, and decreased equipment size and bulk while improving the realism of the radar-indicator display.

Previous attempts were made to solve these problems. The designs resulting from such work have provided much ground work based on combined photographic and electronic techniques. These designs either were never carried to completion or, if completed, were not advanced designs. An Air Force design, very similar to the Navy's Two-Transparency Flying-Spot Scanner technique, described herein, reached the experimental model stage but was afterwards abandoned. Thus, it cannot be stated whether the Air Force system's limitations could have been overcome or not.

Development of the Two-Transparency Flying-Spot Scanner technique, sponsored by the U. S. Naval Training Device Center, has now reached the breadboard stage and is still continuing. This technique, an outgrowth of all the preceding designs, may be divided into two main categories: information storage and information processing. These will be described individually.

Information Storage

Terrain information as used by the Two-Transparency technique is based upon U. S. Coast and Geodetic Survey Topographical charts. These charts show limited terrain information, both natural and cultural, with contour lines denoting the elevation of applicable terrain.

With the charts underneath as a continuous visual reference for registration accuracy, two master overlays are prepared, one for elevation and one for reflectivity-information storage. (Fig. 8.) An elevation gray scale is established, and areas of equal elevation are painted on the elevation master overlay with the same shade of gray. Fig. 9 shows how elevation information is represented. On the other master, areas of equal reflectivity are depicted with the same shade of gray. To develop the reflectivity data, drainage information as shown on the topographical chart is used as a reference level. Reflectivity data on all other terrains must be developed from radar-prediction data, aerial photographs, knowledge of specific terrain features, and the like. The master overlays, with composite map still underneath, are next photographed and reduced to the final transparency size.

The present system utilizes 500,000:1 Lambert Conformal charts reduced to 5,000,000:1 for final transparency size. When normal laboratory photographic developing processes and a commercially available lens are used, the resolution capability of the system is such that objects as small as 200-scale feet in diameter may be detected. Where more detail is required, such as in built-up cultural areas, a more comfortable working scale is desirable. Since Target Complex Charts are available on a 100,000:1 chart, the required artwork is done to this scale on a separate map board and overlay apart from the main composite map discussed previously. This smaller area, when completed, is photographically copied and reduced to the 500,000:1 scale,

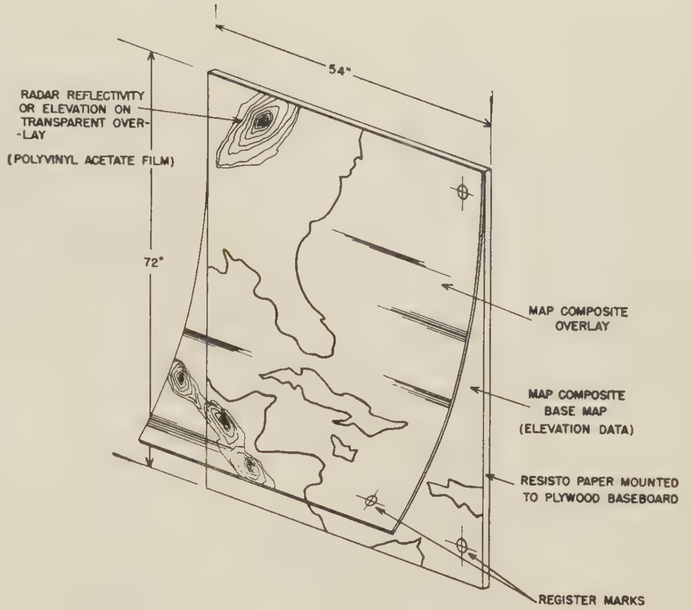


Fig. 8.

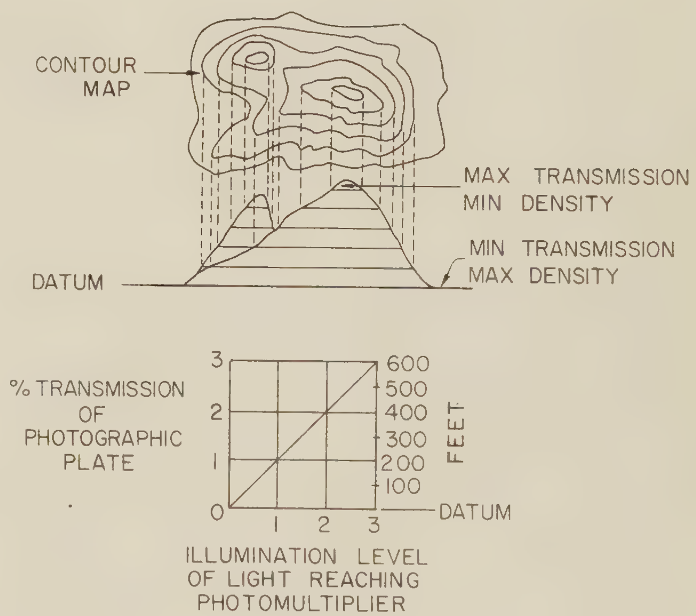


Fig. 9.

and then is attached to the transparent master overlay. This procedure also permits changes to portions of the master overlays as the information becomes available.

Only the basic procedure for the production of the transparencies has been described. It can be seen from the foregoing discussion that improved lens and developing processes, and additional study of a particular terrain can increase the map-area coverage, detail, accuracy, and information-storage capabilities of the transparencies.

Information Processing

It should be apparent that the presentation of information is dependent upon an accurate read-out of the data stored upon the transparencies. A simplified block

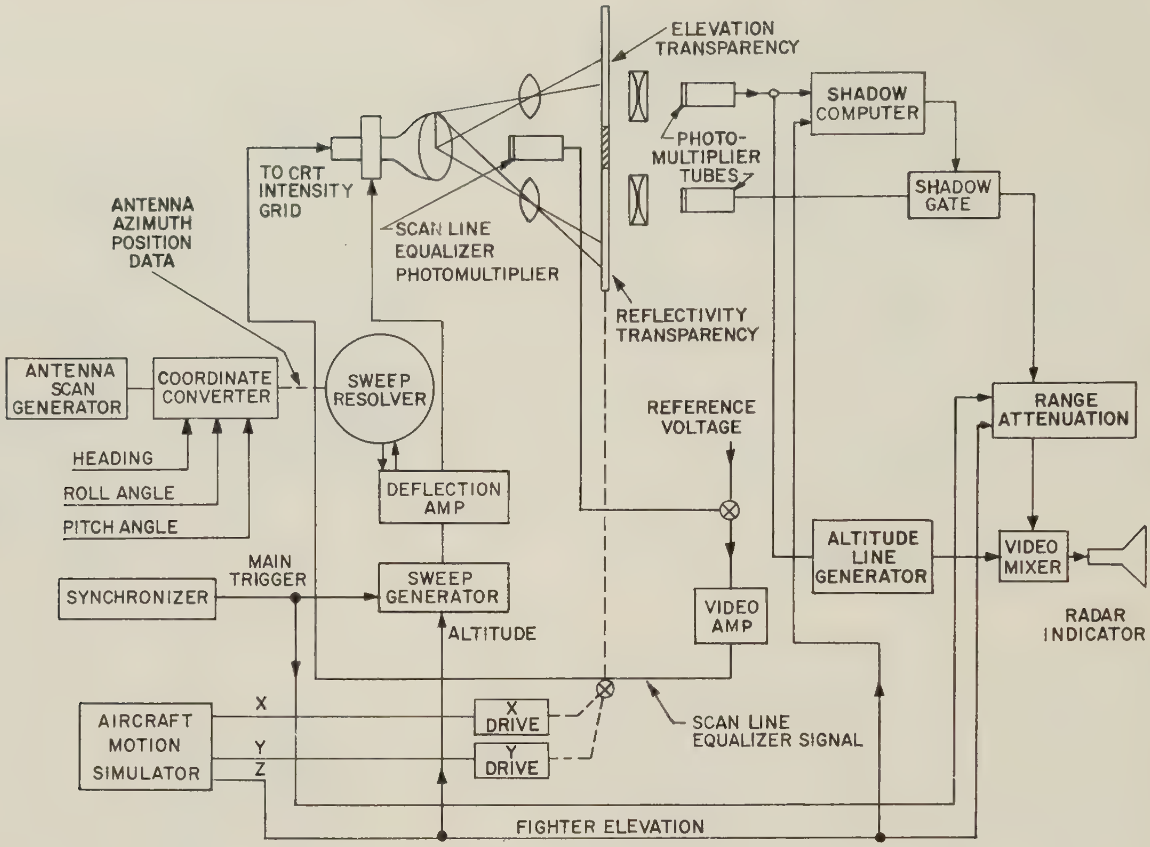


Fig. 10.

diagram of the system used is shown in Fig. 10. It is seen that a flying-spot scanner cathode ray tube, through its optical linkage, illuminates both transparencies. Conventional timing and synchronizing circuits accept information relative to the attitude of the simulated aircraft and the instantaneous position of the simulated radar antenna and then control and synchronize the motion of the scan line to conform to the sweep circuits of the selected radar indicator. Each of the transparencies modulates the light from the flying-spot scanner tube in accordance with the shades of gray painted on each transparency. The modulated light from each transparency is read-out respectively by two photomultiplier tubes. The electrical signal obtained from the reflectivity photomultiplier tube is converted into an appropriate video signal. The information obtained from the elevation photomultiplier tube is used to gate the video signal as computed by the shadow computer. X and Y drives receive signals from an aircraft motion simulator and provide X and Y movement of the transparencies corresponding to a "flight" over the map area. It should be noted that the positions of the flying-spot scanner and photomultipliers are fixed. Therefore, effects due to altitude of the simulated aircraft must be accomplished electronically. Altitude or z-information is fed to the shadow computer, range attenuation circuit, and altitude line generator. Since attenuation with range of the radar signal varies as the inverse fourth power of range, the video signal is passed through a variable-mu remote cutoff tube, where a suitably shaped waveform varies the tube gain as a function of time. The altitude line generator is merely a delay circuit to provide the effect of altitude on the sweep of the radar beam. The scan-line equalizer photomultiplier is a third photomultiplier placed ahead of the transparencies, and in a manner similar to an AVC circuit, it monitors the brightness of the scan line over the face of the flying-spot scanner tube. This circuit corrects for tube defects or nonuniformity of brightness by continually comparing the scanner-tube brightness with a reference voltage to provide correction when required.

It is also noted that shadows are not a natural result of this system as in systems utilizing three-dimensional maps. These radar shadows must be computed electronically, and for that purpose, a shadow-computer and shadow-gate system are employed. This system consists of a computer circuit to cut off the reflectivity signal under certain prescribed conditions. Referring to Fig. 11, if O corresponds to the airborne radar position, then distance downward and to the right is positive, horizontal distance along ground is X, and the slope of the line of sight to any point A is

$$\left(\frac{Z_F - e}{X}\right).$$

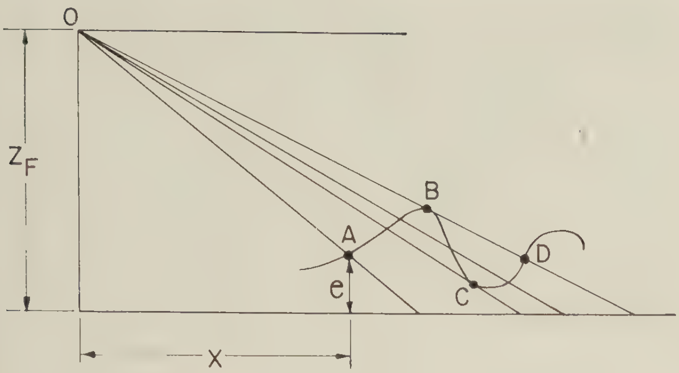


Fig. 11.

The slope of the terrain at any point A is $(-de/dx)$. (Increase in e with X is positive but since the origin is at O, this represents a negative slope.)

A shadow will start at B, which is a point of tangency or slope equality. Before point B, $(-de/dx)$ is generally negative while (Z_F-e/X) is generally positive and (Z_F-e/X) becomes negative only for terrain points higher than the aircraft altitude. Therefore, prior to the start of the shadow

$$\left(-\frac{de}{dx}\right) < \left(\frac{Z_F - e}{X}\right).$$

At shadow start

$$\left(-\frac{de}{dx}\right) = \left(\frac{Z_F - e}{X}\right).$$

After shadow start

$$\left(-\frac{de}{dx}\right) > \left(\frac{Z_F - e}{X}\right).$$

If the comparison of line-of-sight slope and terrain slope is permitted to continue, there will be another point of tangency, and, therefore, another equality established at point C. However, this point is of no value and is disregarded.

The relationships for establishing the end of the shadow no longer require any further information as to the terrain slope $(-de/dx)$. What is required is a memory or storage of the line-of-sight slope at point B, as given by the shadow-start equation. Let us call this quantity $(Z_F-e/X)'$.

Before shadow end

$$\left(\frac{Z_F - e}{X}\right)' < \left(\frac{Z_F - e}{X}\right).$$

At shadow end

$$\left(\frac{Z_F - e}{X}\right)' = \left(\frac{Z_F - e}{X}\right).$$

After shadow end

$$\left(\frac{Z_F - e}{X}\right)' > \left(\frac{Z_F - e}{X}\right).$$

At the conclusion of the shadow, the cycle of operation ends, and the shadow-start equations are again in effect.

Since the elevation transparency is scanned linearly, $X=t$. Terrain elevation is furnished by the elevation photomultiplier tube, aircraft altitude or Z_F is provided in dc form and the shadow start is established when

$$\left(-\frac{de}{dt}\right) = \left(\frac{Z_F - e}{t}\right).$$

At shadow end

$$\left(\frac{Z_F - e}{t}\right) = \left(\frac{Z_F - e}{x}\right).$$

However, the left-hand term is a stored quantity, determined at the instant of shadow start as being equivalent to $-de/dt$. Therefore, it is possible to also store de/dt and apply a prime notation to indicate it is a stored quantity.

This may be restated for the shadow end condition as

$$\left(\frac{de}{dt}\right)' = \left(\frac{Z_F - e}{t}\right) \quad \text{or} \quad Z_F - e = -t\left(\frac{de}{dt}\right)'.$$

Fig. 12 is a block diagram of the basic computer for instrumenting shadow-start and shadow-end equations. Consideration of the above discussion on curve slopes indicates that at the start and end of a shadow, certain equalities are established. Using comparator or Schmitt Trigger circuits to sense the instant of equality, we have a means of generating a gate which, when applied to an electronic switch, would cause the reflectivity signal to go on and off.

Shadow computation, while complex, permits the two-transparency system to avoid one of the basic limitations of the three-dimensional map systems in that there is no minimum altitude at which a simulated aircraft can "fly." In fact, it is possible to compute "flight" at a negative altitude.

Other important effects must be included in any system of land-mass simulation. Some effects, of course, are dependent upon the characteristics of the radar system being simulated. For example, changes in selected radar ranges may be accomplished by mechanically changing the lens system to achieve the desired range effect, or as improved flying-spot scanner tubes become available, by shortening the scan line.

Antenna beamwidth distortion, common to all radar systems, is still a problem to be solved. One solution under investigation is that of intentionally introducing an astigmatic effect on the flying-spot cathode-ray tube. This can be introduced by means of an auxiliary special-purpose focusing coil which will receive a fraction of

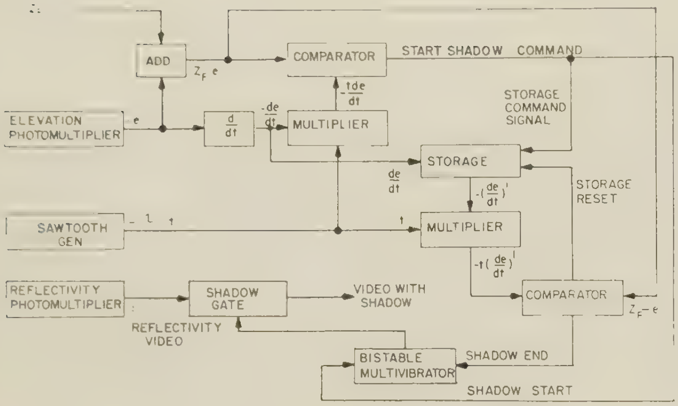


Fig. 12.

the normal sawtooth deflection voltage. The spot-spreading effect will be a function of the spot displacement from the cathode-ray tube center.

Under operating conditions, urban areas, which are normally oriented in a north and south direction, produce stronger returns, or scintillation effects known as the "cardinal point" effect, when approached from one of the cardinal directions. Cultural areas, when approached from one of these cardinal directions of north, east, south, or west present much more area or mass suitable for the direct return of radiated energy. Several methods are currently under investigation for the inclusion of "cardinal point" effect. One method is to store, on a third transparency, the special returns necessary when an urban complex is approached from a cardinal direction. However, it is hoped that additional investigation will prove that the addition of a third transparency will not be necessary, and that the special returns may be included on one of the present two transparencies.

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Development of the First Helicopter Operational Flight Trainer*

EUGENE W. CAIRNS†

Summary—**This paper describes the design and development problems associated with the construction of the first operational flight trainer to simulate a helicopter. Included is a description of the components comprising the trainer along with a discussion of its capabilities and training value for indoctrinating Army helicopter pilots in the flight characteristics of the H-37A Helicopter. Problems in deriving a complete set of motion equations were encountered in the initial phases of the project. These are described as is the approach used in simulating the rotor aerodynamics. The attachment to the operational flight trainer used by the student for visual flight training is also described in detail.**

TOWARD the end of 1955, a requirement was established by the U. S. Army for an operational flight trainer (OFT) which could simulate the H-37A Helicopter, a twin engine, five-blade rotor aircraft used for transporting troops or carrying cargo. The trainer was to be used to train Army Aviation personnel in various phases of helicopter flight training. The task of building the trainer was assigned to the U. S. Naval Training Device Center, Port Washington, N. Y. A contract was subsequently let to Melpar, Inc., Falls Church, Va., to build the required operational flight trainer. It is expected that the trainer will be installed at Fort Rucker, Ala. for utilization by the Army Aviation School in early 1960.

The H-37A Helicopter Operational Flight Trainer with visual attachment is a training device unique in three areas: 1) training potential, 2) efficiency, and 3) training on a no-risk basis. The trainer has built-in controls and indicators which enable a qualified instructor to simulate emergency conditions and provide synthetic environmental conditions which allow tailoring problems to meet specific training objectives. Compared with training in an operational helicopter, the availability of the OFT is higher; weather and darkness do not detract from training potential, and maintenance and operation costs are lower.

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The complete trainer consists of two major devices (Fig. 1): the H-37A Helicopter Operational Flight Trainer, Device 2F54, and the Visual Display Attachment, Device 2FH5. The trainer was designed to simulate the characteristics of the H-37A Helicopter during ground and flight operations, including the sensory effects of cockpit motion and sound simulation. The visual attachment is a device which enables the trainee to fly VFR problems over a nonprogrammed terrain.

The OFT consists of an instructor station, computer zone, and the trainee compartment. The components of the visual display are a light source, suspension system, and a screen.

The instructor monitors the trainee from a control console (Fig. 2) which contains repeater instruments for flight and engine instruments and indicators located in the aircraft cockpit. In addition, variable control setting indicators inform the instructor of the setting of cockpit controls, such as collective pitch stick throttle, overhead throttles, overhead mixture controls, carburetor air controls, and collective pitch stick. By observing indicator lights, the instructor determines whether the trainee is starting the engines correctly, conducting his pre-start, pre-take-off, and pre-landing checks properly, engaging the rotor clutch correctly, or shutting down the engines. Position indicators in the form of indicator lights are provided at the instructor's console for determining the position of various switches and levers in the cockpit. The instructor is warned by indicators if the trainee exceeds limits of the V-g envelope, overspeeds his engine, has an excessive rate of descent on landing, or an abnormal attitude at touchdown. Emergency conditions under the control of the instructor are initiated, monitored, and controlled by the use of ON-OFF switches, multiposition switches, variable controls, and indicators. These elements provide for the simulation of malfunctions and failures in all the aircraft systems.

The trainer has provisions for two instructors to operate as a team. In addition to the instructor's station, there is an instructor's jump seat located directly behind the pilot and co-pilot seats in the cockpit. The jump seat station includes an instructor's freeze panel which enables the instructor to: 1) freeze or reset the trainer, 2) disconnect hydraulic power from the cockpit motion systems, and 3) select various combinations of intercom relationships between the students and instructors.

The computer is a 60 cps electromechanical analog device. All computations with the exception of cockpit motion, visual attachment, and switching functions are performed with a 60 cps signal carrier. Function generation is performed by precision wire-wound potentiometers driven by 60 cps position and velocity servomechanisms. Summations are performed with precision resistances in conjunction with high vacuum tube amplifiers. All integrations are performed with velocity servomechanisms which utilize tachometer feedback for

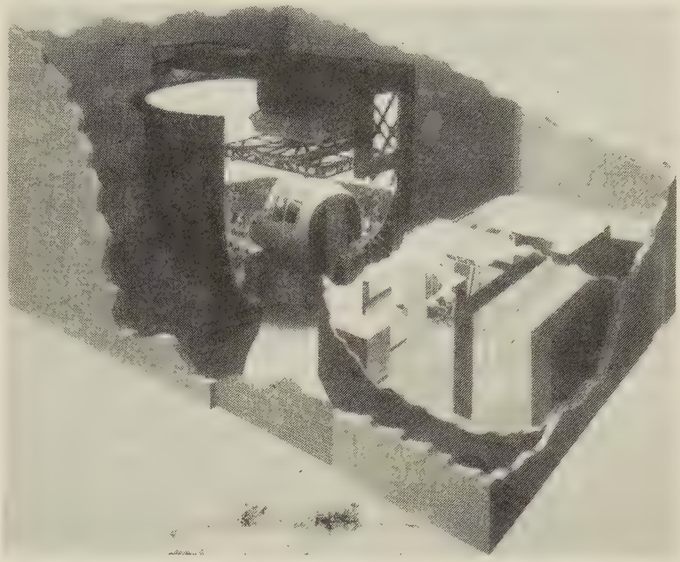

Fig. 1—H-37A Helicopter Operational Flight Trainer and Visual Display Attachment.

Fig. 2—Instructor's station showing control console in center.

velocity control. In lieu of using absolute voltage amplitude to obtain greater system accuracy and stability, the 60 cps analog voltage is ratioed with the basic reference voltage to generate the function analog voltages, making computer performance virtually independent of reference voltage regulation and directly dependent on reference voltage balance in a parallel summation type of computation. The cockpit motion system utilizes 400 cps and dc carrier systems to obtain the high frequency response characteristics of the system. The visual attachment uses a partial dc carrier system to control the hydraulic drives of the projection system. All switching and relay functions utilize 24 volts dc as the signal and power source.

Located within this zone are five 4-drawer computer racks for the aerodynamic, engine, and aircraft systems computation; a power distribution console; a motor generator console; and a power supply rack. The power

distribution console contains controls for the main power, airconditioning and heaters, area lights, computer power, utility outlets, and the communication system. A phase sequence indicator, running time meter, main power ON indicator, power supply ON indicator and computer power ON indicator are also located on this panel. Load applications, with the exception of the radio aids unit, utilities, and lighting are sequenced by an automatic time programmer which applies the various loads in a predetermined sequence at proper time intervals. The system is interlocked to prevent the application of B^+ power to the equipment if the filament, reference, or 24-volt power is disabled. The starting sequence is initiated by momentarily depressing either of the two start buttons located on the power supply rack and on the power distribution panel.

Although the basic philosophy of the flight simulator is to completely reproduce the aircraft characteristics, the limits of computation are governed by what is necessary from a training standpoint. Training value is not necessarily dependent on complete simulation. The H-37A Helicopter OFT does not have continuous computation of center of gravity, but the location of the longitudinal CG as a function of cargo loading is controlled from the instructor's station. Gross weight as a function of cargo loading is also controlled from the instructor's station but is limited to maximum, normal service loading, and minimum gross weights in conjunction with each CG position. Variation in gross weight and CG position is not computed, but a control for adjusting the quantity of internal fuel between zero and maximum capacity is located on the instructor's console. Fuel loading of the auxiliary tanks is also simulated. Computation of the H-37A Helicopter attitude up to $\pm 85°$ in pitch and roll is simulated for instrument flight conditions only.

The Radio Aids Unit (Device 1D5) realistically simulates navigational, communications, and instrument landing facilities. This equipment is located at the instructor's station on either side of the instructor's main console. It consists of three cabinets: 1) the flight path and altitude recorder, 2) the instructor's operating controls and repeater instruments, and 3) the position computer for range and bearing. The radio and navigation equipment contained in the operational H-37A Helicopter, and simulated by the Radio Aids Unit, are the AN/ARC-44 (Interphone and FM Liaison), ARC Type 12 (VHF Command Set), AN/ARN-12 (Marker Beacon), and the AN/ARN-6 (LF Automatic Direction Finder).

Probably the greatest problem associated with the development of this trainer was that of defining a complete set of equations for helicopter motion that would cover both hover and forward flight. The equations used in industry for hover and forward flight are linearized, and for the most part, simplified. Equations of motion used for this study, because of fewer basic assumptions, were much more complete but permitted more exact simulation of hover and forward flight.

Four different orthogonal coordinate systems are used in the H-37A Helicopter OFT: the inertial system, fuselage system, shaft system, and the blade system. The inertial system is fixed in space and permits the location of the aircraft with respect to a fixed position on the earth's surface. The earth is considered flat at all times, and the effect of the Coriolis force is not considered. The other three systems originate in the various rigid bodies comprising the aircraft.

One problem area in the formulation of the equations was that of choosing an approach to follow in analyzing the rotor system. After carefully surveying the existing methods used by the helicopter industry and other research organizations, the blade element approach was chosen. In this method, 24 stations were selected in the disc area swept by the blades; *i.e.*, four radial positions for every 60° in azimuth. These stations do not move in time; they always maintain the same azimuthal and radial position. Both the tangential and normal instantaneous velocities are computed at each station. The angle of attack is then computed, taking into consideration the position of the blade pitch controls. Using this information and actual airfoil data, incremental lift and drag are calculated. Components of lift along the three fuselage axes and drag and flap torque are developed by using properly weighted lift and drag increments. Flap torque is then expressed in a Fourier series and inserted in the flap angle differential equation, thus properly influencing the flap angle.

The blade element approach allows the calculation of hover in a straightforward manner without modifying the basic equations. Blade stall is included because the simulation of incremental lift vs angle of attack includes stall. Mach number effects on minimum drag are included, as well as the variable distribution of inflow velocity. A prime drawback to this approach is the necessary assumption that the blades are rigid. Blade elasticity is a known phenomena, but there are no techniques available for introducing this effect into the equations. Another problem is the continual variation of velocity along the blade. The technique employed in the trainer assumes that the blade stations do not interfere with each other.

The blade element method reverts to fundamental aerodynamic analysis, calculates the lift and drag at a particular point, and sums them over the entire rotor disc. The rotor blade is twisted normally. Further, the pitch and angle of attack of the whole blade may be varied with the flight controls. To calculate the angle of attack properly, it should be separated into two parts: 1) that due to velocity of a zero pitch, untwisted blade through the air, and 2) that part due to the twist and control stick. The first part is called the inflow angle

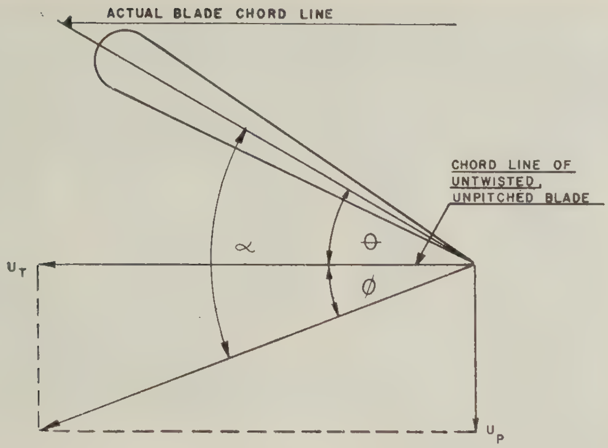

Fig. 3—Angle of attack at a blade section.

and is calculated by an arctangent process as shown in Fig. 3. U_T is the tangential velocity of the unpitched, untwisted blade, and U_P is the normal component. The equations for U_P and U_T are written by using appropriate direction cosines. In the equation for U_P, local induced airflow velocity is introduced and is considered normal to the untwisted blade. Having calculated U_T and U_P, the inflow angle is given by

$$\Phi_{\psi-y} = \arc\tan \frac{U_{P\psi-y}}{U_{T\psi-y}}$$

where the ψ and y subscripts locate the point in question as to azimuth and radius position.

Angle of attack, α, is given by

$$\alpha = \phi + \theta$$

where θ is the effect of twist and control lever action. The control lever operates fore, aft, and sideways in a continuous fashion. The fore and aft cyclic pitch change also produces side forces. For this reason, a fore and aft motion of the control stick is phase-shifted to give the effect (in cyclic pitch) of a slight sideways stick motion simultaneously. In the trainer, this shift is $7\frac{1}{2}°$ but is so inserted as to be easily varied should the trainer's dynamic characteristics differ somewhat from the aircraft's.

Vector airspeed is given by

$$U_{\psi-y} = \sqrt{U_{T\psi-y}{}^2 U_{P\psi-y}{}^2}.$$

This equation illustrates one major assumption of the blade element approach, which is that airflow in the direction of the span is ignored.

Lift coefficient (C_L) and drag coefficient (C_D) simulations were made on the basis of a preliminary study.

Contour plots of α and Mach number were made, then replotted as α vs MN for $V=0$, 40, 100, 140 knots at sea level, and 15,000 feet altitude. Maximum and minimum points were found and then divided into collections of constant Mach number. Then plots of α vs C_L parametric in these Mach numbers were made from airfoil data. These plots were each simulated by a single function. Drag coefficients were simulated in the same manner.

The visual attachment allows the trainee to fly the simulator visually over an area $2\frac{1}{2}$ miles wide and 10 miles in length, up to an altitude of 1000 feet. An auxiliary landing area is also provided and is approximately one-half mile by $2\frac{1}{2}$ miles. The trainee normally has no access to this area. The instructor provides freedom for the student to enter into this area. The position of this landing area can be programmed by the instructor. On leaving the usual flying area, the student enters into a fog condition with the maximum ceiling set anywhere from 100 feet to 1000 feet and must continue his flight on instruments.

The device utilizes the point light source technique for projecting the terrain image onto a curved screen. A 100-watt Osram lamp is used as the light source. The light source diameter is controlled from 0.045 inch to 0.006 inch according to altitude. The point light source diameter is important from image brightness considerations since the number of candles emitted from the source is dependent upon the diameter and is one of the most important factors which affects image brightness. In this particular device, the light source intensity varies from 18 candles at a source diameter of 0.045 inch to 40 candles at a source diameter of 0.0006 inch.

An 18-foot radius screen is located in front of the cockpit and gives the trainee an angular terrain coverage of 200°. The screen is fabricated from fiberglass-impregnated plastic and spray-covered with beads. Various screen materials were investigated and tested in order to determine the most suitable material from the standpoint of screen brightness, in this case, reflected brightness varying between 0.3 foot-lambert and 0.5 foot-lambert. The screen gain is two, and is defined as the factor by which the projected image is made brighter than a perfectly diffusing screen of identical size and shape. The screen contour closely approaches an elliptical curve, the design criteria being that which gives zero velocity distortion.

The flexible transparency which depicts the terrain is made of Mylar, and is 45 feet long by $8\frac{1}{2}$ feet wide. Mylar was selected because of its flexibility, good optical clarity, toughness, receptivity to dyes, resistance to scratching, and high ultimate strength. The hand-decorated transparency depicts a flat terrain, and the scenery consists primarily of landing areas, farm areas, roads, lakes, and forests. Three-dimensional objects scaled 2000:1 are cemented to the transparency. The three-dimensional objects are programmed so that circumferential grooves cut in the main rollers allow the objects to pass around the roller without interference. The transparency travels from one storage roller to

another, the linear speed being controlled carefully by servo systems. Vibration is damped by the use of soft bristle brushes fixed in the vicinity of the point light source and a special transparency tensioning system.

Motion of the point light source is accomplished by a double arc cam arrangement of gears resulting in pitch and roll sensations. Rotation of the transparency frame simulates yaw, while movement of the transparency simulates longitudinal motion. The suspension frame for the above equipment is shown in Fig. 4.

The combined devices will be installed in the air-conditioned building approximately 60 feet long and 50 feet wide. The OFT portion is a self-contained unit with a 15-ton airconditioning unit. A vestibule located on one side of the OFT can be used as a briefing room for training pilots. The vestibule houses the OFT air-conditioning equipment, visual attachment computer and power supply racks, and the hydraulic unit for the visual attachment. The remaining portion of the building houses the cockpit, screen, and projection system. The cockpit motion system and the two-ton capacity cockpit airconditioning equipment (Fig. 5) are located beneath the cockpit. The cockpit entrance is located at the rear.

It is significant to note that although the initial requirement was for a training device, the development of the H-37A Helicopter OFT has opened areas of simulation previously unexplored. Since no appreciable amount of flight data was available, a very general approach to equation formulation was attempted, along with a rigorous investigation of the blade element theory to rotor simulation. The visual display was designed with the object of reducing the adverse effects of previous visual displays, both of the point-light source type and also television presentations. Other research tools which attempt to simulate helicopter flight in limited areas have been built or are presently being built. However, the H-37A OFT is truly the first complete helicopter operational flight trainer ever developed to fulfill the task of training pilots not only in emergency procedures and instrument flight but in recognizing the aerodynamic effects peculiar only to helicopter operation.

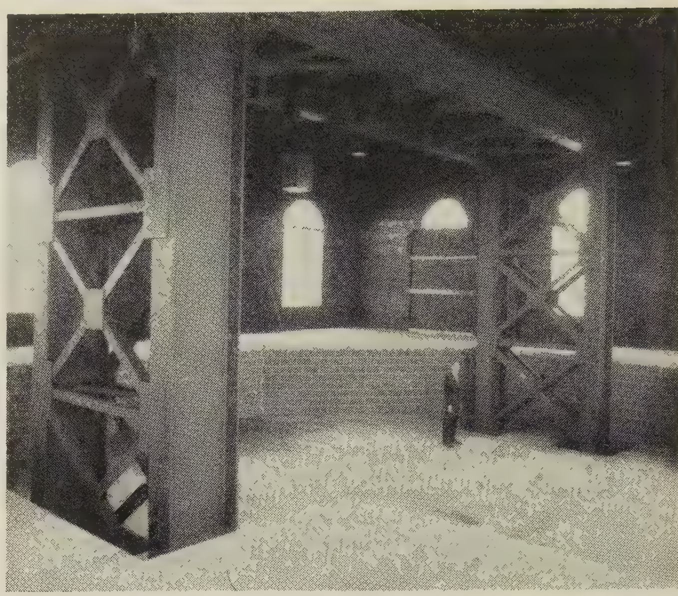

Fig. 4—Suspension frame for point light source and transparency frame.

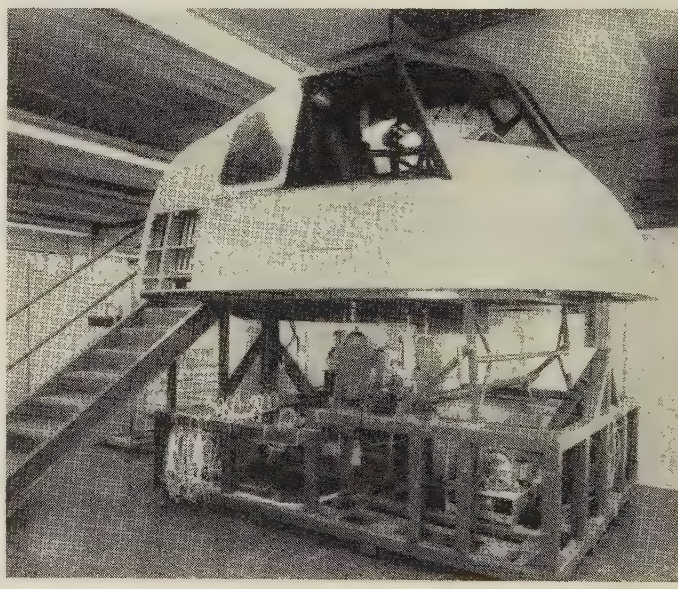

Fig. 5—Trainee cockpit mounted on base frame including entrance stairs and showing cockpit motion equipment and airconditioning unit.

Simulation of Earth's Topography for Research and Engineering*

S. DOMESHEK†

Summary—**This paper explains the present methods of simulating the earth's topography and their uses, the difficulty and time consumed in making some of these simulations, and the limitations of their uses. It then explains the need for some better method because of the greater volume of topographic information required in greater detail because of the needs of cold war, national defense, industry, road expansion, seaway expansion, airport construction, radar site construction—all to be done in a great hurry. It leads up to the automatic terrain model system. It explains quickly the several systems that were considered and why the printed circuit system was chosen. It mentions the fact that the information is stored on magnetic tape and utilized to carve a three-dimensional terrain model, and then goes into detail as to the greater information that this particular system can provide automatically that cannot be done except through extensive hand calculation with the other systems.**

OF the long existing simulations of earth's topography, probably the first to come to mind are the conventional, litho-printed, contour maps (Fig. 1), which are the first of the modern earth simulations. For research and engineering, however, these maps generally serve as intermediate tools in the preparation of other more specialized topographic descriptive media. The aerial photograph (Fig. 2), the second of the modern earth simulations, similarly serves only as an intermediate tool in the preparation of more specialized topographic descriptions.

The direct engineering applications of conventional maps are based on the ability to obtain direction, distance, projected area and shape, and, for the sophisticated user, three-dimensional visualization of topography from a reading of contours alone. Similarly, the properties of aerial photographs permit direct identification of terrain cover, estimate of trafficability, the conduct of timber and crop surveys, and industrial and other economic and geological analyses. Through stereoscopic observation of pairs of aerial photographs, an excellent three-dimensional visualization of the terrain covered may very readily be achieved.

Each of the simulations described above provides distinct direct applications which are often complementary. However, even when used together, they are limited to the direct applications described above.

For most engineering and research purposes, conventional maps and photographs require additional work before engineering and research data can be obtained. Thus, some of the most important applications up to this time, such as the calculation of volumes of water backed up by irrigation and flood control dams, the preparations of profiles for use in road building, railroad layouts, etc., are all derived, or indirect applications of maps. These derived applications, by conventional methods, are difficult, time-consuming tasks, even when both maps and photos are available.

The great volume of world-wide road building and airport construction, increased urban and suburban building, gigantic industrial expansion, and mammoth seaway, irrigation, flood control, and hydro-power projects have placed a premium on speeding site and route evaluation and earth-moving calculations. More exotic needs have been added to these classic research and engineering applications of maps and photographs, such as:

1) Microwave transmitter relay location.
2) Television transmitter siting.
3) Radar site selection, radar prediction and simulation.
4) Undersea modeling for oceanograghic research and defense.
5) Gravimeter and magnetometer survey analyses.

Thus, the urgency of establishing communications nets and detection systems for national and western defense has been added to classic map applications.

With these newer, exotic applications has come a new and increasingly popular method of simulating the earth's topographs; namely, the reproducible overprinted terrain model (Fig. 3). This may be used directly for finding direction, distance, projected area and shape, terrain cover, trafficability, and industrial, economic, and logistic analyses, since terrain models combine the quantitative character, in three dimensions, of the contour map with the qualitative detailed descriptions of the aerial photograph.

But more important, the use of terrain models speeds site and route evaluation, calculations of valley flooding and earth moving, transmitter location, radar prediction, range analysis and simulation, and military planning (both tactical and strategic), on a *direct* basis. However, with all their advantages in making the various earth quantities explicit, terrain models are the most difficult earth simulation to obtain. The process by which they are prepared requires special photoprinting apparatus, plastic forming equipment, the preparation of molds, and the making of master models. Since increased volume of terrain models is demanded, hand-made master models can no longer be tolerated. The reasons for this are apparent: 1) the method is too slow, 2) accuracy is too low, and 3) there must be a means of using source maps, regardless of their specific projection or scale. Fortunately, a solution to this problem is in sight.

The Automatic Master Terrain Model System being developed by the U. S. Naval Training Device Center

* Manuscript received by the PGMIL, April 15, 1959.
† U. S. Naval Device Center, Port Washington, N. Y.

Fig. 1—Typical topographic map.

Fig. 2—Typical aerial photograph.

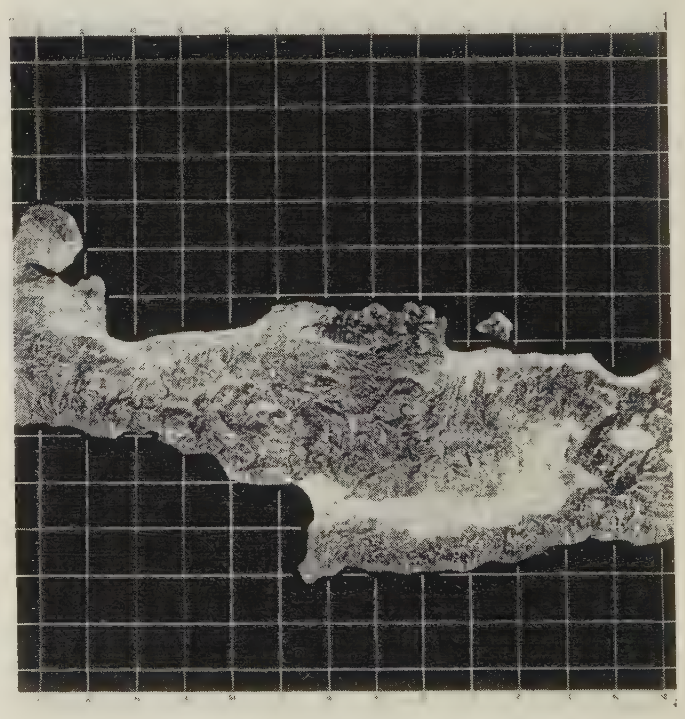

Fig. 3—Typical photo-surfaced model.

aims at the preparation of a terrain model from a topographic map in which each element of the system operates automatically and receives its instructions from the preceding element automatically. Fig. 4 illustrates the system both schematically and photographically. At the left, a topographic map is automatically scanned; coming to the center, the scanning signals are transformed in a SPOMEDIC computer and made suitable for recording as digital quantities on a magnetic tape. On the right, through a control console, the data on the magnetic tape is fed to a power pack which controls the motions of a cutting unit which carves the terrain model.

The system is not in the contour follower category, but is rather a profile scanner and generator. Automatic contour following systems have been designed and built previously. But these generally have been aimed at working with input data in the form of mechanical drawings in which the lines to be followed are regular in shape and are not too close together. In topographic maps, such conditions are not prevalent. The contour lines are not regular, and their spacing may in some instances be such that the lines almost converge.

The profiling technique was suggested, since mechanical and electromechanical systems perform most accurately and most rapidly when the paths they follow have a minimum of change. In this fashion, instead of having both X and Y vary almost continuously while Z, the altitude, is kept constant, as is the case with contour lines, only Z varies while X is a constant-rate, straight-line motion, and a Y advance occurs only at relatively few intervals.

Thus, in terms of simplicity and reliability in an overall system, profile scanning and generation offer the greatest potential since the pattern of paths required both to scan a map and generate a model are geometrically simpler. In profile scanning, the oscillations of a

Fig. 4—Composite of master terrain model system.

line representing a slice of terrain are less in amplitude if the line represents a vertical rather than a horizontal slice. A simple proof can be seen by examining Fig. 5, showing a system of typical ridges that may be encountered. In any traverse of the ridges, the frequency of oscillation of the line describing the traverse is determined by the number of ridges in the system. But, the amplitude of those oscillations is a function of whether the traverse across the ridges is maintained in a horizontal plane or in a vertical plane, since the amplitude is much greater for the horizontal rather than the vertical traverse.

An equally important consideration in the solution of the problem is the necessity of obtaining slope automatically. This in itself was a factor influencing selection of the vertical profiling technique over the horizontal contour scan, since straight-line interpolation between contour lines provides sufficient semblance of continuous slope of terrain and requires no other finishing operation. On the other hand, to interpolate a number of other auxiliary contour lines between the existing contour lines of a conventional map in as small as ten thousandths of an inch interval, would require a tremendously uneconomical effort without the slightest bit more fidelity in terrain shape.

Once having made the decision to build a profile rather than a contour system, the problem arose of how to prepare a map so that it could simply be fed into the input end of the system and automatically have the system accomplish its own scanning, transforming of data, and carving a model. This problem was one of the most crucial encountered in the development of the entire system.

This same problem is also crucial to the simulation of earth's topography for research and engineering in general. Consequently, the remainder of this article will be concerned with the map-scanning solution and its several applications.

In examining the various possibilities for profile scanning, criteria were first set up against which the best of these possibilities could be measured and selected.

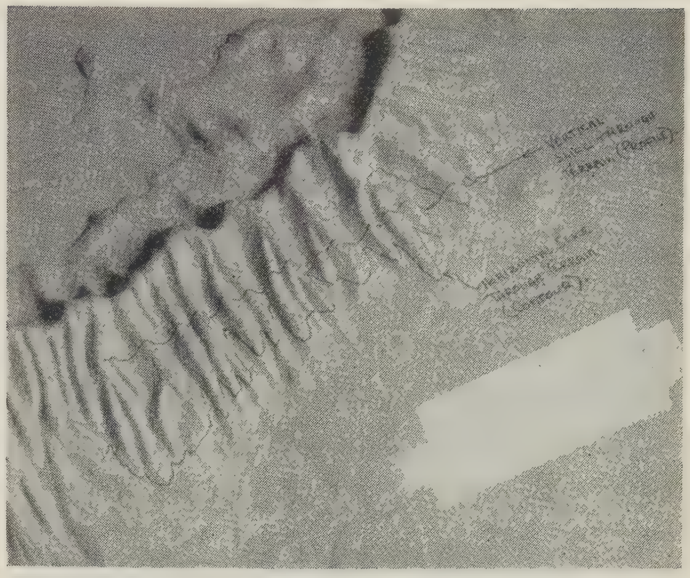

Fig. 5—Relative amplitudes of oscillation per horizontal and vertical traverses over typical terrain.

These criteria consisted of the following:

a) First of all, there must be no ambiguity. The map must let the scanner know when the terrain is going up or down, and it must be able to handle the discontinuities in terrain which occur at the edge of a topographic map. Any map sheet containing contours that can be dealt with must of necessity be only a small section of the earth's surface and must, therefore, have at the edge of the map the arbitrary discontinuities mentioned.
b) The system selected should allow minimum time for preparation of the map so that it can be scanned automatically.
c) The scanning system selected must permit full automatism. There should be no need for an operator to stand by to guide the machine at critical points.
d) The system selected must be capable of providing fairing information in a fully automatic fashion and of an authentic character. (Fairing is generally accomplished in terrain models by the interpolation of slope between contour levels so that the finished terrain model provides a natural appearance rather than the impression of a series of steps.)

One of the first techniques investigated was that of transforming a conventional topographic map into a photo-etched copper-plate analog of that map. This system had already been used for a NAVTRADEVCEN training device in which it was necessary to have one part of the training device sense the elevation of a target on the terrain so that the necessary corrections could be fed to a ballistic computer, and correct gun elevation obtained to allow a simulated projectible to strike the target. In considering this method of scanning it was recognized that brown-line contour maps could be obtained (without extraneous data) which would be

Fig. 6—A map with ridge and drain lines of inflection.

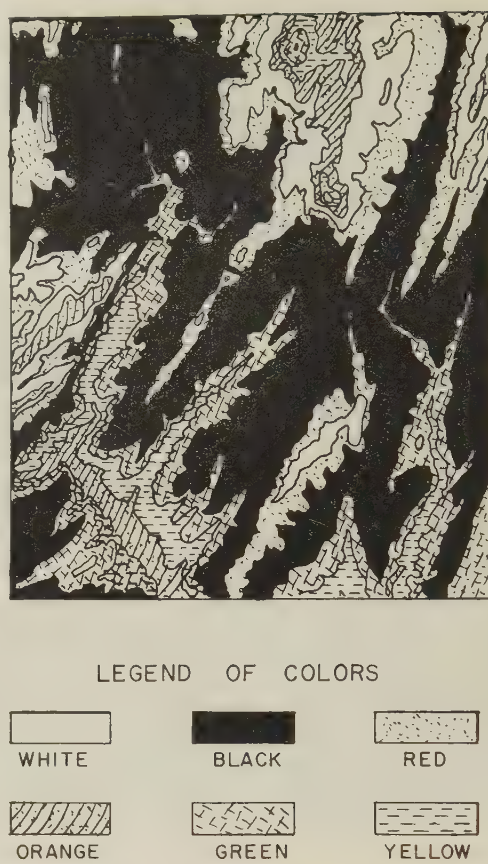

Fig. 7—Color coded map.

used to prepare the photo-etched copper analog. However, this technique was not adopted because it did not offer in itself a means of interpolation of slope between contours, and because it would require the use of an expensive photo-engraving process.

The second profile scanning technique investigated utilized one of the essential properties of terrain: namely, the existence of lines of inflection (Fig. 6). Just as a point of inflection on a plotted curve signifies a change in the character of the curve, so may a line of inflection be plotted on a topographic map to signify a basic change occurring in the character of the terrain. For example, a stream is a line of inflection on terrain because any line, until it reaches the stream, has a downward slope, and as soon as it crosses and departs, has an upward slope. Similarly, ridge lines are lines of inflection. Any line crossing a ridge, until the time it reaches the ridge line, has an upward slope; after it crosses and departs from the ridge line, it has a downward slope. This concept for profile scanning seemed to have the potential of minimum map preparation, since the contour lines were already on a sheet and the stream drainage pattern was also available for conventional printing on a sheet. The only additional work to be done consisted of plotting the ridge lines and coding the contours at the edge of the sheet so that the machine would not lose track of where it was in scanning. However, such work in plotting would require a highly skilled topographer or geomorphologist; the system did not provide directly for automatic fairing; and it left itself open to ambiguity where the line of scan paralleled the line of inflection. (Topography being what it is, it was not possible to select an orientation of map with respect to a scanning system such that this type of parallelism could be avoided.)

The third possible scanning technique investigated was one using color bands (Fig. 7). In this concept, each contour level is given a discreet and contrasting color from its adjacent contour levels. To avoid ambiguity, at least three different colors have to be used so that color sequence itself becomes the indicator of upward or downward slope. The application of colors to the contour levels can only be manual, indicating that a very considerable period of time is required in preparing the map for automatic scanning. As a matter of fact, the amount of time involved approximates that of cutting a terrain model directly from a topographic map when pantograph machines are used. Furthermore, fairing would have to be mechanically generated in the system through an elaborate apparatus, rather than by a property inherent in the map.

The foregoing were the major concepts investigated as profile scanning systems. However, there were others (Fig. 8). The use of discreet gray tones was investigated and rejected for reasons similar to those rejecting the color band idea. Continuous gray tones were thought of as a technique, but their attainment presented difficulties as great as the primary problem of preparing the terrain model automatically.

Fig. 8—Gray-banded contour map.

Finally, on re-examination, the photo-etched copper map plate technique was chosen (Fig. 9). The reason for the choice was the suggestion of an idea by which the map input itself might not only provide automatic and reliable information on height at a point, as well as vertical direction, but also the slope between contours.

Each contour line of the photo-etched copper map-plate was given a different electrical resistance, and all contour lines of the same elevation were connected through the back of this plate to assure the same voltage over the entire plate for any given contour line. The idea which prompted another look at the copper-plate method was that of coating the scanning surface of the copper map-plate with a thin, even, resistive coat which permitted interpolating elevations of points between contour lines by measurement of the incremental voltage between contour lines as a proportional function of the distance of the point between contour lines. Thus, slope was generated directly and automatically by the contour plate as it was being scanned.

The problem of the cost of photoengraving is still present, but the photoengraving technique has been adopted because it: 1) requires a relatively low level of manual labor in connecting contour lines of the same elevation, thus keeping time required for map preparation to a low level; 2) provides a nonambiguous, fully automatic scan; and 3) provides, inherent in the map itself, a slope determination feature.

Having devised such a new simulation of earth's topography as a tool for the automatic preparation of terrain models, the properties built into the copper map-plate lend themselves to other direct applications as well. Thus, by programming the scanner of the Automatic Master Terrain Model System along the proposed route of a railroad or a road, optimal grading can be determined, and earth removal and filling can be calculated directly in the SPOMEDIC computer. For flood control and irrigation projects, the volume of water that may be impounded behind dams can be calculated readily through scan of the affected areas of the copper map and integration of the volume between the earth's surface and the water surface at the top of the dam.

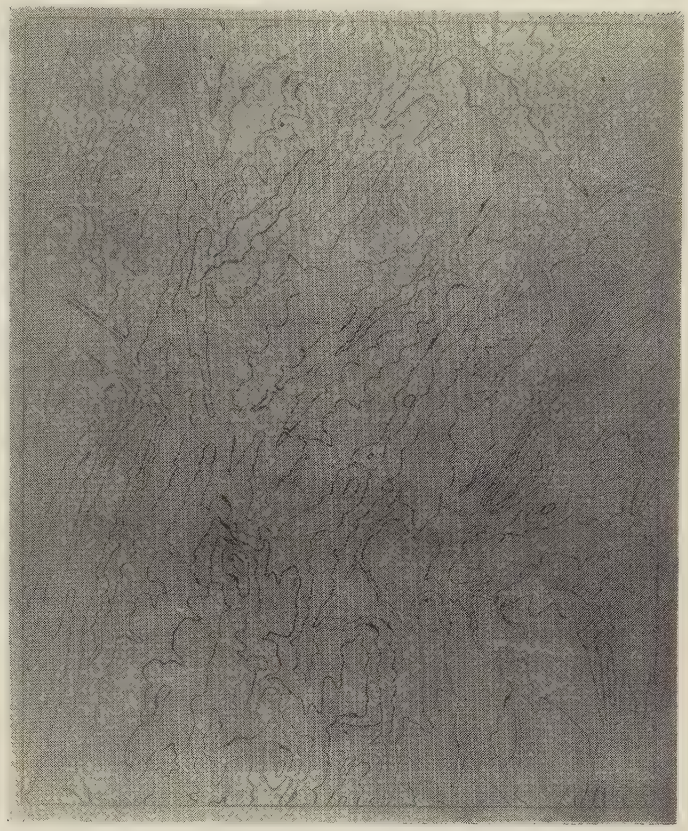

Fig. 9—Photo-etched copper map.

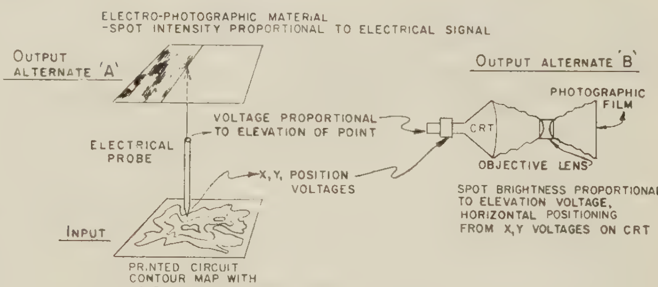

Fig. 10—Preparation of continuous tone photo-map (schematic).

Finally, by scanning this same copper map with an electrical probe (Fig. 10), voltages proportional to elevation at every point can be obtained as before, and through electro-optical or electrophotographic transducers, a continuous-tone photomap may be obtained by purely automatic means. This map can then be used as a high fidelity, continuous tone, visual representation of change in elevation of topography. Such a continuous-tone photomap is also of value today in various radar prediction and simulation systems.

An Integrated Space-Flight Simulator*

MORRIS ACKERMAN†

Summary—The role of the flight simulator in the space vehicle program is presented in this paper. Application of a simulator as an engineering and development aid is the subject of the discussion. A simulator for training the space crew is anticipated and therefore is mentioned in passing.

A brief review is made of contemporary thinking regarding anticipated physiological and psychological effects on the future crew. A simulator is then defined which will integrate these effects, thus providing a complete environment for experimentation.

Early phasing of the integrated simulator with the space vehicle is suggested as a better foundation for design of the space cabin or capsule than sole dependence on feedback from early flights.

Introduction

THE role of the simulator in training pilots and crews for aircraft is established and well known. Simulators will probably play a similar part in the training of pilots and crews for space vehicles. In the space vehicle program, however, there is need to expand the role of the simulator into a two-phased operation. In reverse order, the second phase will require the familiar simulator trainer or operational flight trainer to be utilized specifically for indoctrination training and proficiency measurement. The first phase will require a simulator for research and development of the space vehicle, in particular, the cabin or capsule.

It is recognized that there are many experiments under way requiring simulation. These experiments apply to all aspects: environment, acceleration, weightlessness, psychological, physiological, control, display, etc.

The purpose of this paper is to describe a first-phase simulator which will integrate the results of these experiments.

This device will make it possible to run experiments in a complete vehicle cabin under nearly complete environmental conditions. Experimenting with a complete simulator early in the man-in-space program will provide essential data which can aid design decisions affecting the man in the cabin. The alternative is to provide feedback from early test flights to the engineers who will insert revisions into subsequent vehicle models. Unfortunately, this process is risky and costly. Furthermore the cabin design never seems to catch up [6].

The Phase I research simulator can be progressively modified to become the Phase II training simulator. Another solution is to program two simulators, one for each phase. Changes for the Phase I device could be added to the specification for the Phase II trainer. This paper, however, will be devoted to the Phase I research simulator.

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Systems

A brief review of those elements of the space environment and vehicle which might affect the pilot or crew is now in order. For this discussion, a vehicle will be assumed which is capable of earth launch, flight to another planet, orbit around this planet, and return to earth for re-entry and landing. It is convenient to consider these elements in terms of the following systems:

- Propulsion
- Flight
- Environmental (internal):
  - Pressure
  - Temperature and humidity
  - Air
  - Food Supply
  - Waste Disposal
  - Shielding
  - Acceleration and weightlessness
  - Sounds
  - Sights
  - Furnishings
- Communication
- Navigation.

A good starting point is the propulsion system. In near-to-earth craft such as airplanes, the parameters of the engines are well known and have been simulated many times. Emergency features, such as air starts of jet engines, have been simulated and play an important part in training devices. The first generation of manned space craft probably will be launched automatically. Separation of stages is automatic and probably will continue to be automatic for some time. It is probable that the human will be added to the control loop to assist the optimization and discrimination processes. The mere fact that his brain is a computer utilizing miniaturized components in a small package will no doubt tempt engineers to add him to the loop. For emergency conditions, engineers will attempt to provide various controls for manual operation. The simulator provides an excellent test bed for this type of research because of the expense and time consumption of real flight experimentation. Control of verniers under partial power conditions, emergency restart of engine after failure, and introducing new engines for changing direction of the vehicle in orbit are possibilities.

The flight system, like the propulsion system, probably will have a combination of automatic and manual controls. The analog of this system will not be difficult; it should be simpler than present aircraft flight analogs wherein flight equations are complicated by aeroelastic

and Mach number effects. The simplicity of this analog, however, will disappear when the vehicle capsule attempts to return to earth. It will leave the earth as part of a missile configuration and return with a different look not unlike a high-speed aircraft with many of its aerodynamic problems. Flight control after launch by the human appears inevitable. Change of direction in interplanetary space will require controls to be designed for the pilot and crew. Re-entry will require considerable control because the vehicle will be returning to the realm of aerodynamic flight. Simulation of these parameters will only be a problem if accuracy of extremely large ranges of integration is a problem. Because a man, with his limited ability to withstand large accelerations, will be in the vehicle, ranges of acceleration are not expected to be a problem.

The internal environment is defined to include all systems which have to do with the comfort and well-being of the pilot or crew, as well as sensory perceptions such as sound and sight.

Pressurization of the cabin is somewhat of a controversial issue. The use of one atmospheric pressure is proposed by some; others propose less than one atmosphere, but how much less is not clear. Simulation of any habitable pressure is feasible. Simulation is desirable in order to check the pilot's or crew's proficiency in a number of tasks under different pressures. Other variables enter the picture. For example, levels of oxygen and nitrogen depend on this pressure [1]. Because loss of cabin pressure is expected to be a major hazard in space flight, the design and test of emergency procedures and equipment to overcome this situation appear most necessary. It appears that slow leaks are more to be feared than sudden decompression. Therefore, means of detection and follow-up correction procedures will be mandatory. The simulator will provide an excellent test facility for wring-out of such designs.

Temperature and humidity controls inside the cabin will be a major problem because of what may happen to the exterior surface. Radiation from the sun and earth, transfer of heat generated by the pilot or crew and equipment, and heat induced by re-entry to the atmosphere, are all factors. The simulation of these conditions, especially as more data are obtained from space experiments, can be accomplished without too much difficulty. Considering that the human skin pain level is about 113°F, adequate simulation would not be damaging to the device. This simulation is desirable to study reaction, emergency procedures, appropriate displays or indicators, and handling of other tasks under different temperature levels and combinations of other stresses [8].

Even the space man must eat. The inclusion of feeding apparatus in the simulator is desirable for several reasons:

1) Testing of various food systems or stores while the crew performs routine tasks

2) Observation of results of abstinence or reduced food intake under emergency conditions

3) Testing of closed systems involving growth of food such as algae would be ideal in conjunction with performance of normal tasks.

There could be a relationship between the interest and stimulation of the long space flight and the type of food desired by the crew. It is possible that the flight would be so routine and monotonous that the crew might yearn for exotic foods: algae a la mode, egg foo algae, to name a few. As with feeding devices, the testing and observation of waste disposal apparatus should be a part of the program.

Many problems of providing an atmosphere conducive to proper breathing have been faced in aircraft design. Spacecraft design adds the factor of time; *i.e.*, breathing air must be supplied for a much longer period. The use of pressure suits with breathing apparatus seems to be in order for early space flights. However, a space-vehicle cabin which will provide an atmosphere wherein the pilot or crew can work without uncomfortable space or pressure suits will be much more desirable. In either case, the simulation of this atmosphere presents no problem. The need for simulation hinges on the requirement to have the crew accomplish their tasks under various conditions. The test of emergency procedures for this system, or in combination with other system emergencies, looms as an important feature.

Shielding of space personnel against external hazards, as well as internal radiations, due to a form of nuclear propulsion, presumably will be part of the basic structure of the cabin. Ways and means of completely protecting the occupants are not clear at this time. As more data are made available it may be possible to program the flight in such a manner as to avoid lethal radioactive doses. We can assume that measuring equipment will be on board. The use of measuring equipment will therefore be essential. Assuming the pilot or crew will have control of flight, then this equipment takes on operational importance. Serious exposures apparently cannot be detected by humans until the damage is done. It is likely that a combination of shielding and flight programming based on data obtained from test probes will provide a reasonably safe mission. Simulation of equipment and procedures for monitoring this equipment appears to be a valid requirement. If the crew is small, then automatic warning equipment may be necessary which will require human engineering in the simulator before the flight.

Acceleration or weightlessness will always prevail in the space environment. The performing of tasks under varying accelerations, including zero, is considered to be tricky. A multitude of difficulties have been defined [7]. Even the practice of eating and drinking will require painstaking efforts. The practicability of control designs under the condition of weightlessness should be determined before the space flight. Under emergency condi-

tions, the ability to remain oriented will be a challenge because it will take practice for the human to adapt to this type of environment.

Simulation of acceleration or weightlessness in a complete cabin is quite difficult. Fortunately, simulation of complete weightlessness may not be necessary. Due to the multitude of problems concerning both the man and the vehicle equipment, much attention has been given to means of introducing a slight amount of force on the cabin occupants by some form of rotation [7]. Use of external force provided by the propulsion system has also been suggested [7]. A further extension is proposed which would use a propulsive means to slightly modulate the theoretical flight path by a sawtooth or sinewave motion giving the crew a slight, long period acceleration followed by a slight, short period deceleration.

In contrast to the problems of simulating acceleration, sounds in the cabin are equally as important but relatively easy to reproduce. Known in simulation circles as a "proprioceptive effect," realistic sounds provide a giant step toward deluding the crew into thinking they are on a real flight. The following sounds come to mind as possibilities for multiaural reproduction:

Engines (all stages)
Air (during atmospheric flight)
All cabin equipment
Communication noises (static, interference)
Cosmic particles striking the shell
Noises peculiar to emergency conditions.

Visual surroundings do not pertain to internal items which the operator can see such as controls, lights, and furnishings. We refer here to visual sensations of the external environment as might appear through a window or canopy or on a television screen or radar scope. We speak here of window or scope because the early space vehicles, confronted with little human radiation problem, may not have windows. These sensations should be simulated for several reasons. First, navigational equipment will utilize star or planet sightings. Second, the use of visual simulation will do much to create the impression of reality. Third, the sensation of acceleration may be enhanced by accurate visual presentations. This may be important if acceleration effects cannot be introduced economically. Fourth, there is a need for providing orientation to the crew to combat restlessness (described further on) and the effects of zero "g" environment. For these reasons, an artificial reference may be superimposed on the window or scope.

An accurate picture through the window or on the scope will be very essential during orbital flight or during the return to earth's atmosphere and subsequent landing phases. During space flight, the picture may be relatively monotonous but nonetheless important. The calculation and prediction of the window or television pictures should make for an interesting project in the early simulators built prior to the man or television in-space flights.

The category of furnishings is a catch-all which includes the following:

Structural features of the interior
Furniture: chairs, tables, lounges, bar, etc.
Accessories: ash trays, cabinets, etc.
Auxiliaries: power units, standby air supplies, etc.

These items are easy to provide or simulate and are necessary to enhance the reproduction of the interior of the cabin.

Related to this category are the problems of rest, relaxation, and loneliness. There is a need for activity in these areas: performance of the mission, recreation, and communication with earth [2]. Monotonous flights may create a restlessness in the crew that could be a hazard. Two solutions are suggested: One is to provide a structural setting with ties to familiar customs and surroundings. The other is to duplicate, as well as possible, the diversity of experience possible in life on earth [2]. These requirements for testing various solutions to such problems under nearly-real flight conditions, wherein a multiplicity of features may be duplicated, highlight one application of an integrated simulator.

Means of establishing familiar references such as a horizon or planet are necessary to minimize anxiety in the crew. Various solutions to this problem can best be determined in conjunction with normal and emergency procedures. Artificial references are definite possibilities.

The use of old-fashioned navigation procedures (hand calculations and plots, manual sighting of planets, star and sun) has been suggested in order to provide activity for the crew [3]. This is an example of the need to test more than one parameter. Use of automatic navigation may appear desirable for many reasons but not for some others, such as this one.

Description of Simulator

In consideration of the various systems discussed thus far, the integrated simulator can now be described. Fig. 1 shows a simple block diagram of this device. Fig. 2 presents a sketch of one possible configuration of the integrated simulator.

Beginning with the vehicle cabin or capsule, we assume a most desirable situation. The capsule is shown as a sealed cabin with a complete and automatically controlled environmental system. This allows the crew to work and rest efficiently without being hampered by pressure suits. Early space craft will probably resemble cockpits and will not be nearly as comfortable. A two-man crew is visualized for long flights to offset loneliness and, in case of emergencies, to provide for standby assistance.

The capsule or cabin will contain all instruments, scopes, navigation and communication equipment, engine and flight controls, window or television screen,

and all controls for the various environmental systems mentioned earlier. The interior of the cabin will appear completely realistic. All packages, "black boxes," facilities, equipment, etc., will be duplicated. The cabin should be designed to "plug-in" to the computer and console to provide relatively quick interchangeability.

Sounds in the cabin will exactly duplicate the real noises described earlier. Vibrations resulting from all sources will also be copied. If the cabin is expected to have a window, a screen will be placed in front of the simulator cabin which will present the proper panorama in front of the window. If a television screen is utilized, it will present the proper picture. Visual simulation is a major undertaking worthy of a separate paper and therefore will not be pursued herein. The state of this art is such that either a completely optical projection system or a television optical (videoptic) system is feasible. If a television screen is used in a cabin rather than a window, then a televised solution may turn out to be the proper choice. Fig. 2 shows the window configuration. If television only is used, this screen will be unnecessary.

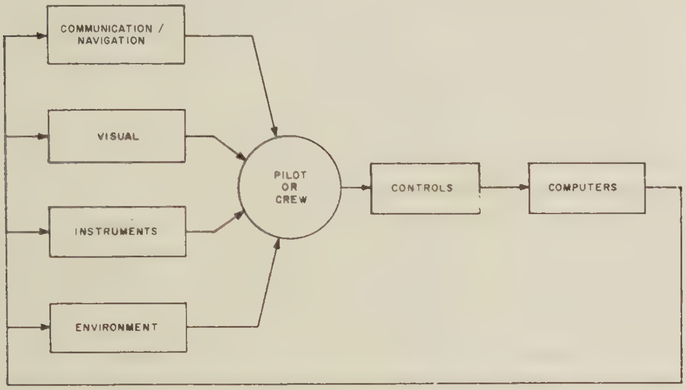
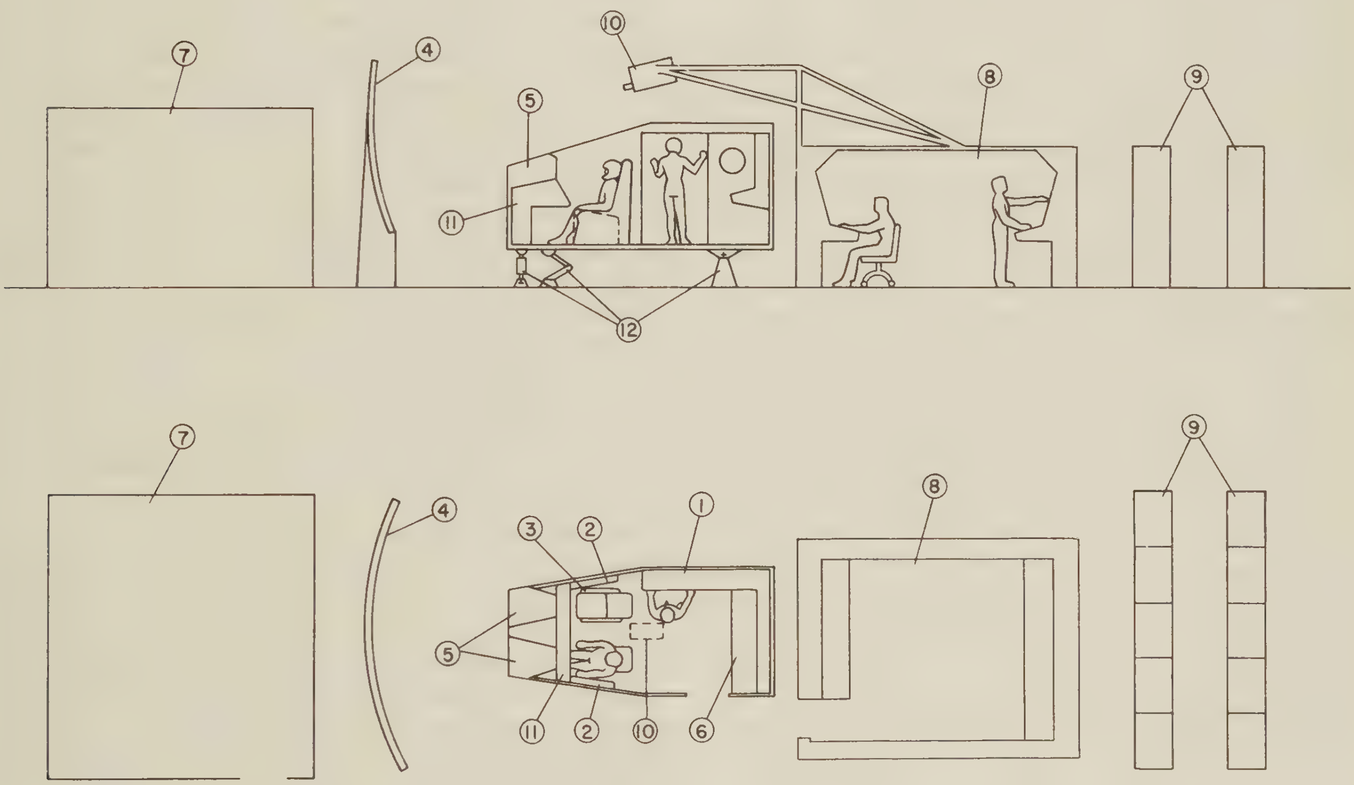


Fig. 1.

It would be very desirable to reproduce the slight amount of acceleration mentioned earlier. The obvious solution is to use a centrifuge. Here, the complete simulator cabin is whirled around. The signals between the cabin and the computer will be routed through slip ring contacts or possibly telemetered. In this fashion, simulation of a space vehicle using similar rotation may be obtained. Other solutions may be less costly but not as realistic. Pressurized suits have been used to give the sensation of "g" force. This is accomplished by applying



1. EQUIPMENT RACK
2. CONSOLE
3. FINGERTIP CONTROLS
4. SCREEN
5. WINDOW OR SIMULATED SCOPE
6. REFERENCE
7. VISUAL STUDIO
8. INSTRUCTOR'S STATION
9. COMPUTER RACKS
10. PROJECTOR
11. INSTRUMENT PANEL
12. HYDRAULIC PITCH AND YAW SYSTEM

Fig. 2.

pressure at appropriate portions of the body such as the stomach, arms, and legs when "g" forces are to be introduced. This system is not accurate, particularly for zero "g" conditions. A novel solution to this problem was suggested by an engineer who once worked with the author. In essence, electrical probes were to be placed at or near nerves at the base of the skull, spine, small of the back, and soles of the feet. Impulses to these nerves would give the effect of "throwback"" or "throwforward" induced by acceleration. Here again the effect would be less than accurate, not to mention possible nerve or physical damage.

The "marionette" approach has also been mentioned. In this solution, wire and linkages in a space or flight-type suit pull or push at the arms, legs, stomach, and neck in consonance with the "g" force to provide the approximate effects. Under a high "g" condition, for example, it would be very difficult, with this contraption, to raise one's arm or move a leg.

For the first space simulator, it is proposed to use a combination of visual references and cabin motion to give a hint or illusion of "g" forces. Cinerama movies have shown that using the visual picture as a reference, the viewer can "feel" the acceleration. This response, plus initial cabin movement, is at least a partial solution that does not require excessive costs.

Adjacent to the cabin will be the researcher or instructor console and the operator's console. The researcher console will be designed with the flexibility necessary to allow a scientist or engineer to monitor the particular program under test. The researcher console will need ample facilities for recording and monitoring data. The need for the researcher to observe the crew may present a slight problem. It is difficult to put the researcher adjacent to the crew without providing unrealistic distractions. The use of ports or mirrors is a possibility. It is believed here that a television pick-up would be more desirable. The only problem here is the placing of the camera in a position which would not distract the crew. The same console would eventually be converted to an instructor's console after the task analysis is derived. The task analysis of the crew can be generally outlined as follows:

Prebriefing environmental conditioning
Final briefing countdown in vehicle cabin
Final vehicle countdown
Take-off phase during increasing acceleration
Rise phase during constant acceleration
Orbit
Lunar or interplanetary flight
Lunar or planet orbit
Return to orbit
Re-entry into atmosphere
Landing
Debriefing.

From that which has been described thus far, the nature of communication and navigation equipment to be included in the vehicle cabin takes on added significance. The necessity of contacting the earth now carries psychological overtones in addition to the basic requirement of reporting mission progress. These overtones include the association with familiar people on earth to avoid anxiety and the association with earth experiences to reduce restlessness. Communication from earth may play a part in the relaxation cycle. The space cartoons many years ago showed television-type pictures in the cabin while streaming through space. This may not be farfetched.

The simulation of all types of electronic communication and navigation equipment is not complicated. On the other hand, optical-type navigation equipment will require a visual presentation of stars, planets, or sun in order to provide a means for obtaining sightings and readings.

The design of the computer will present some challenging problems. They are mentioned here only in passing because the solutions may be the subjects for several papers. Velocity along the flight path must range from 0 to 30 mps or more. A velocity of 28.3 mps can be expected toward the end of a trip to Venus [4]. A flight from Earth to Venus may cover a path distance of 250,000,000 miles [4]. If it is necessary to measure altitude at the beginning and end of this flight within 25 feet, then we have an integrating ratio which is well beyond performance of presently employed dc integrators [5]. The possibility of providing discontinuous computation occurs. The determination of reference axes will be important. The switching from one set of axes to another may reduce the need for large ranges of integration. This may be analogous to the practice of nagivation by using earth as one reference, the sun as another, and then the destination planet as still another.

Acceleration rates should not present difficulties because the vehicle will be designed to take off or land without exceeding 9 or 10 "g" under normal conditions. This performance can be met by present ac or dc computers [5].

Accuracy of position necessary over long flight paths can be determined by an analysis of the performance of the vehicle system. It is likely that navigation will be accomplished by star, sun, or planetary fixes and appropriate flight corrections. This may reduce the need for impossible accuracies in the simulator. If performance data indicates a high degree of accuracy is required, digital computers may be added to the analog computer stable.

Flexibility in the computer racks will be a requirement. The amount of flexibility should be determined when the specification is written. Rather than provide a large range by use of patch board arrangements, it is suggested that this capability be minimized. For example, computers based on switching specified terms from one pot to another are recommended. While researching on

one set of equations, a new set can be derived and pots designed and switched to replace those pots no longer desired. Like a projection slide changer, we can observe one slide while discarding the slide already observed and replacing it with a new one. There may be more clever ways of providing flexibility, but it is suggested that the amount of flexibility be minimized to keep costs down and performance up. The use of large banks of general purpose computers with maximum flexibility for changes is discouraged because of the inherent tendency to deviate from good simulation practice. The inclusion in the simulator of solutions to equations with better accuracy than the vehicle's performance is encouraged, and should be deliberately included in the specification.

Phasing

Phasing of the simulator with the flight vehicle is critical because it will be necessary to provide for the utilization of this device in the research and development phases of the vehicle projects. Contemporary aircraft simulators are designed using estimated performance data based on wind tunnel coefficient data. As flight test data becomes available, the simulator is modified accordingly. These aircraft simulators are programmed to be delivered before delivery of operational aircraft. For example, the KC-135A simulator built by Erco was delivered to Castle AFB before approval of the operational aircraft. Simulators are presently procured on this schedule. Apparently, the need for a real prototype simulator to be delivered much earlier in the aircraft program has not materialized. One reason for this is that present simulators are programmed for training purposes only.

A general specification for this simulator should be prepared as part of the initial design study competition. If more than one approach to various portions of the vehicle are recommended, efforts should be made to provide for each solution in the simulator. It is conceived that a detailed specification would be prepared as soon as preliminary performance reports and configuration drawings were available. This may result during the design study or in the engineering phase after award of the contract.

The accumulation of data cannot be overemphasized. It should begin during the design study and continue during these early preliminary report phases. It should overlap the period of preparation of the specification to provide feedback for accumulating data. The responsibility for accumulation of data, which will subsequently be approved for use in design of the simulator, should only be given to an experienced simulator manufacturer. If this is done, the chances of success of this proposal will be substantially increased for the following reasons:

1) Estimated or wind tunnel data provided by the airframe manufacturer is not always available in the form necessary for simulation. For example, a plot of drag coefficient (C_D) vs lift coefficient (C_L) is usually available, but a plot of drag coefficient (C_D) vs angle of attack (α) is more suitable. To avoid unnecessary delay, the simulator manufacturer must be consulted as to the most desirable form of data. Space vehicle data may take on new forms as a result of the extreme ranges of parameter and new reference axes, as mentioned previously.

2) The majority of data will not be available at the airframe manufacturer's facility. This data must be obtained from the multitude of equipment manufacturers. Much of the systems equipment mentioned earlier will be provided by subcontractors. Again, the data is not always available in the form necessary for expeditious simulation. To provide the proper format, each contractor must be made acquainted with the simulator manufacturer's requirements.

3) In cases where data is spotty or just cannot be made available, deliberate assumptions can be made which will result in minimum design changes when such data becomes available.

By introducing the simulator manufacturer early in the program, it will be possible to overlap the accumulation of data with the preparation of specifications, thus making it possible to begin simulator design at the earliest possible date. It is suggested here that the simulator will be available approximately 15 months after all data is accumulated and approved. This phasing will provide a simulator during the formative research and development engineering phase, well ahead of the first manned vehicle flight.

Utilization

Given the integrated space flight simulator phased well in advance of delivery of the space vehicle, there are many uses that can be anticipated.

In the area of human factors, the simulator will augment the use of part task research experiments by providing a means of testing under conditions where a number of interrelated variables can be controlled. For example, the crew's reactions on a time basis to combinations of controls and instruments during the return to orbit or the re-entry into the atmosphere can best be evaluated in such a device. Any chronic low proficiency scores by the pilot or crew under test can be noted in time to revise the design before the prototype flies. The integrated simulator may well be the only available flight "test bed" in early man-in-space programs.

The feedback of data from the full-scale simulator to the engineering and design groups is another application of this device. Many new aircraft simulators have provided significant data during the "flight" acceptance tests. The author has noted that a number of flight test pilots, both civilian and military, "play" with the simulator by setting up unusual or emergency problems which would never be attempted in the aircraft. In one

case, a hurried long-distance call was made by the pilot after such a session to his company's group engineers.

Psychophysiological tests can be made in this device under full-flight conditions. Many tests can be made such as determination of effects of oxygen, pressure, and temperature variation on the pilot or crew while performing tasks. An interesting situation occurred during Man High II [9]. The air regeneration system malfunctioned but Simons, although a trained medico, apparently was not aware of it. Neither was he aware of the significance of his respiratory rate, which he quoted as 44, well above the normal of 12 to 18. The CO_2 concentration in the cabin had risen above the maximum acceptable level. While emergency measures were being taken, the system began to function normally. This loss of insight might be enough to endanger the mission. Should communication with earth physicians be interrupted, malfunction of the air system might not be detected until the flight is ruined. The need for automatic warning of abnormal respiratory rate, dangerous CO_2 concentration, or related parameters is suggested here. The integrated flight simulator will provide an excellent means for testing and proving designs of such warning systems.

The observation of loneliness, isolation, and other psychological factors during a fully simulated mission can readily be accomplished. Feedback to the engineering groups will again be appropriate.

Repetitive reviews of complete missions should improve the efficiency of the cabin system design in the areas of feeding, sleeping, relaxing, and communicating.

During preliminary flight tests (without man) the simulator might be coupled to the telemetered flight test data in such a way that the cabin will duplicate what is happening during the flight for visualization purposes. Or, the data could be recorded and a playback made using the simulator.

Conclusions

1) A simulator is recommended to augment individual, part task, general purpose computer experiments. This device will provide the capability of research and development under controlled conditions resembling space environmental expectations. The observation of all interrelated functions will be possible despite the lack of space flight experience.

2) The space simulator conceived herein is recommended to integrate the multitude of environmental chambers, control simulators, displays, etc., during the research and development engineering phases of the vehicle project.

3) The integrated space flight simulator should be constructed as early as possible in the engineering phase of the space vehicle program and be modified intermittently to keep current with the vehicle design.

4) The simulator manufacturer should assist in the preparation of specifications as well as shoulder the responsibility for accumulating data necessary for simulation.

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The Human Disorientation Device—A Simulator of Angularly-Accelerated Motion*

JOHN H. ACHILICH†

Summary—**The Human Disorientation Device has been developed as a research tool in the field of aviation medicine for the generation of angularly accelerated motion to enable the accomplishment of medical research in the field of animal or human responses to angular acceleration.**

The device will produce accurately known and controlled values of angular acceleration about two axes of rotation when the subject is seated so that his head is located at the point specified by the intersection of the axes.

The Human Disorientation Device will allow medical research in the field of sensory responses to angular acceleration, vertigo, and similar phenomena required for an analysis of human behavior and human performance limitations in the rapid maneuvering (spin and tumbling, etc.) of high-speed aircraft and spacecraft.

THE Human Disorientation Device is a simulation research tool in the aviation medical field designed to generate angularly accelerated motions to enable medical research to be accomplished on animal and human responses to angular acceleration.

The device was developed by the U. S. Naval Training Device Center, Port Washington, N. Y., and the McKiernan Terry Corporation, Harrison, N. J., for the Bureau of Medicine and Surgery, School of Aviation Medicine, Pensacola, Fla.

The device will produce accurately known and controlled values of angular acceleration about the two axes of rotation when a subject is seated so that his head is located at the point where the horizontal and vertical rotational axes intersect (see Fig. 1).

As a result of the continuing increase in the performance specifications of aircraft and the inevitable introduction of spacecraft, it is imperative that information be obtained on the resulting increase in the incidence of angular accelerations and its effects upon humans subjected to it. The effects of angular accelerations can impair a pilot's coordination to such a degree that he will be incapable of controlling his aircraft or spacecraft.

Broad investigations as to the magnitude of the physiological effects, thresholds, and influences modifying the thresholds are necessary so that efforts can be made to counteract the disorientation of humans from Coriolis forces associated with movement under all possible conditions of rotation.

The Human Disorientation Device will permit medical research in the field of sensory responses to angular acceleration, vertigo, and similar phenomena required for an analysis of human behavior and human performance limitations in the rapid maneuvering (spin and tumbling, etc.) of high-speed aircraft and spacecraft.

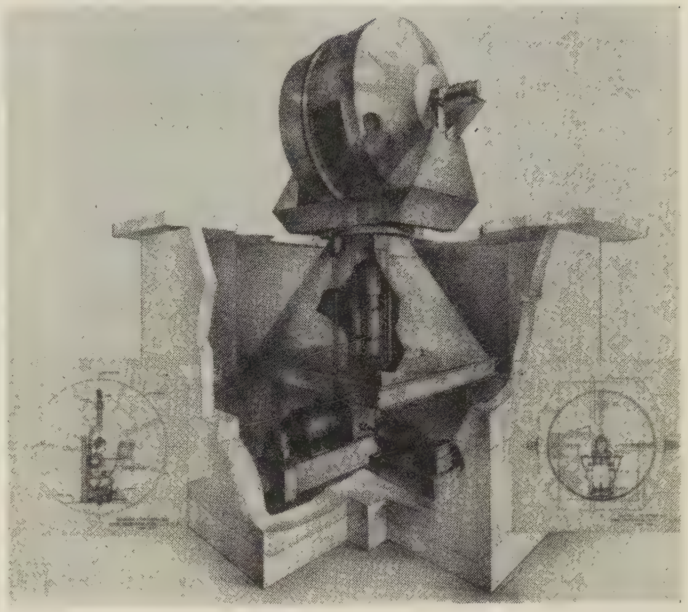

Fig. 1—The Human Disorientation Device, over-all view and location of human subject.

The device's operational characteristics are as follows:

1) Rotation about either horizontal or vertical axes and simultaneous rotation about both axes.
2) Two ranges of speed of 300 to 1 each:
   a) *Range 1*—0.02 to 6 rpm capable of accelerating between $0.1°/sec^2$ and $30°/sec^2$.
   b) *Range 2*—0.2 to 60 rpm capable of accelerating between $1°/sec^2$ and $300°/sec^2$.
3) Electronic speed control through use of a high accuracy reference and electronic preamplifiers, in conjunction with tachometer generator feedback and adjustable voltage control.
4) Shielded conductor system for furnishing electrical signals from rotating test enclosure to recording equipment.
5) Programming of device, both manual and automatic. Each axis capable of being programmed independently or simultaneously.
6) Test enclosure, including a prepositioning adjustable seat for containing the subject in any desired position, relative to a central location of the head.
7) Instrumentation for the measurement of angular acceleration, angular velocity, position, torque, and physiological data.

The device is located in a two-story building at the U. S. Naval School of Aviation Medicine, Pensacola, Fla.

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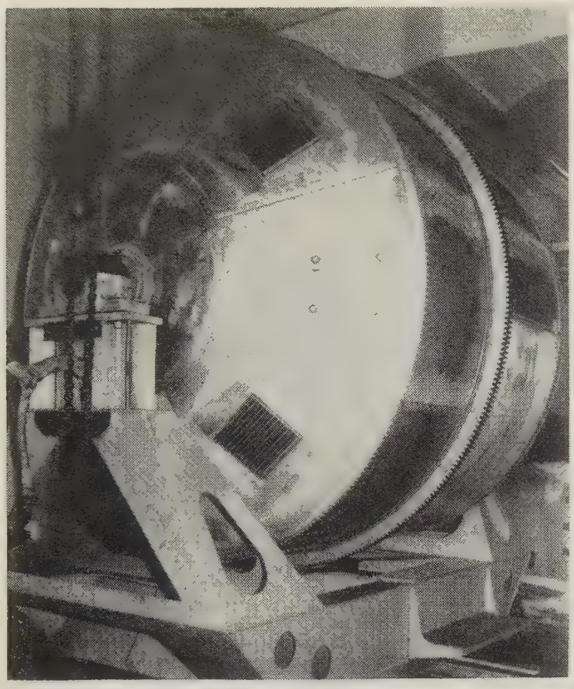

Fig. 2—The Human Disorientation Device, test enclosure, and yoke assembly.

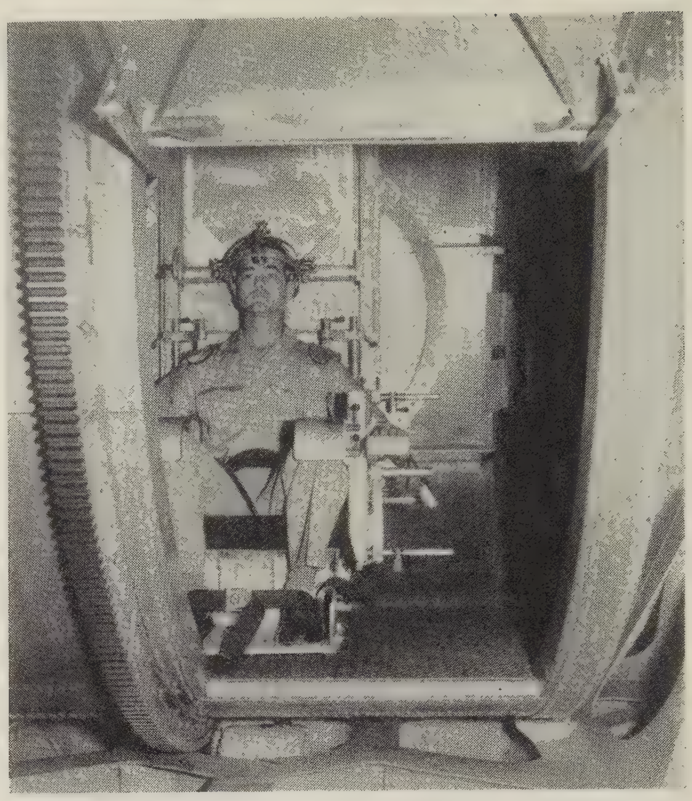

Fig. 3—The Human Disorientation Device, interior of test enclosure through door; with adjustable seat and subject contained therein.

The ground floor of the building supports the complete device. The electrical and mechanical drive units are also located on the ground floor. The device test enclosure and its supporting yoke extend from the ground floor to the second floor of the building. The device's control desk, automatic programmer, calibration console, and patch panels are also located on the second floor.

The device test enclosure (see Fig. 2) contains the subject and is controlled in both the horizontal and vertical axes. The enclosure, constructed of aluminum (stressed skin construction) is a cylinder which measures 8 feet $\times$ 8 feet. The interior of the test enclosure contains the adjustable seat for a human subject or animal table. The test enclosure is entered by means of a hinged door. Various patch panels are located within the enclosure for attaching recording and power circuits. A ventilating and lighting system is incorporated within the enclosure.

A large ring gear is fitted about the circumference of the test enclosure and enables horizontal rotation to be imparted to the enclosure.

Drain outlets are incorporated in the shell to provide a means of cleaning the interior of the test enclosure. Removal of the enclosure floor plates allows the complete interior to be flushed and cleaned.

Incorporated within the test enclosure is the adjustable seat (Fig. 3) provided for the human subject. The adjustable seat assembly is supported in a "C" frame structure which is attached perpendicularly to the test enclosure floor. This structure allows the adjustable seat to be prepositioned with respect to the vertical axis of the device.

The adjustable seat assembly which bolts to the "C" frame structure allows the seat assembly to be prepositioned along the horizontal axis of the test enclosure.

The centerline of the subject's head is located at the centerline of the device's vertical axis. The centerline of the subject's ears is located at the centerline of the device's horizontal axis. In varying this prepositioning of the subject, the point of intersection will remain fixed, while the subject's axes will change position. In other words, the pivot point of the adjustable seat assembly can remain at the intersection of the horizontal and vertical axes, permitting innumerable patterns of rotation about either horizontal or vertical axes, or combined horizontal or vertical axes.

An open-type helmet assembly supports the subject's head. Four adjustable and self-locking clamped pads support and retain the head circumferentially every 90° in the plane of the forehead. An additional pad support retains the top of the head.

The sides of the seat are adjustable to fit the subject (minimum of 24 inches to a maximum of 42 inches), as well as the rib support pads, shoulder support pads, knee supports, and foot supports. The entire seat assembly is adjustable 7 inches in elevation.

The subject in the seat controls readiness of the testing operation by using the "Subject Ready" switch located at his fingers on the adjustable seat. Appropriate interlocks prevent the test from beginning until the subject actuates this switch.

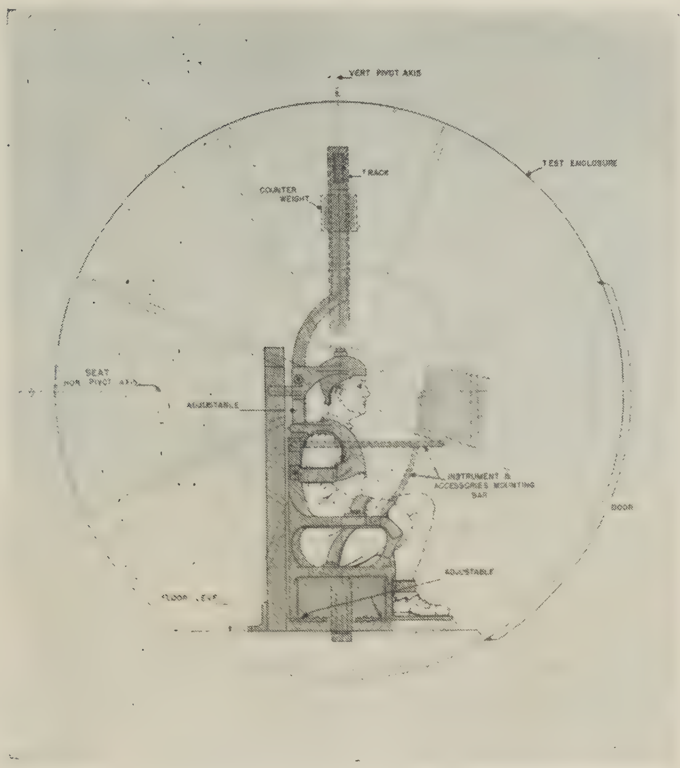

Fig. 4—Preliminary design concept of adjustable and positionable seat, Human Disorientation Device—(9-U-35)—side view.

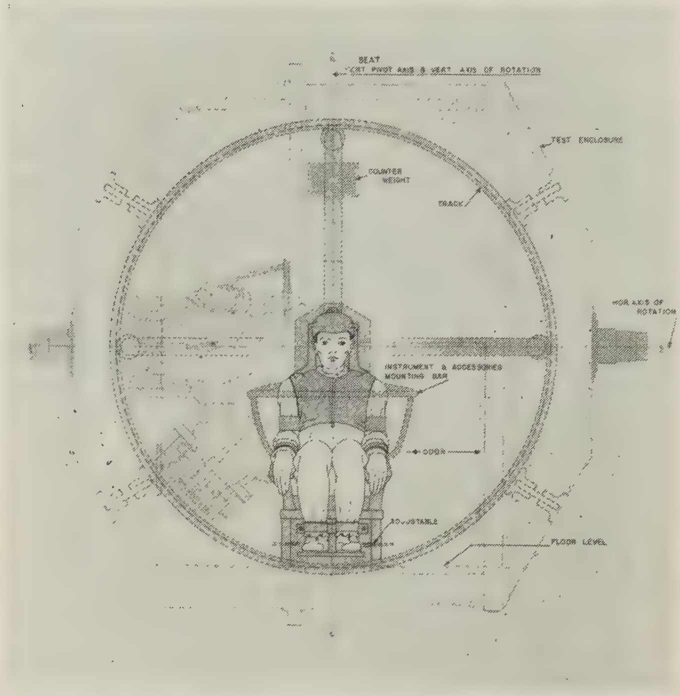

Fig. 5—Preliminary design concept of adjustable and positionable seat, Human Disorientation Device—(9-U-35)—front view.

The adjustable seat assembly is designed to completely support the human subject's torso, so that the rotations and angular accelerations can be applied safely. The adjustable seat itself or the adjustable seat assembly and "C" frame supporting structure are entirely removable from the test enclosure (see Figs. 4 and 5).

Attached to the adjustable seat assembly is a tubular aluminum structure which supports test instrumentation, television, and movie cameras, etc., at approximately the subject's eye level to obtain information from and monitor the subject's reactions. The support is hinged to allow the subject access to the adjustable seat.

The test enclosure is balanced both statically and dynamically by attaching weights, as required, to the inner surface of the enclosure. With the inclusion of the adjustable seat, subject, and test equipment, weights are oriented on the upper portion of the adjustable seat assembly to accomplish balancing. By mathematical analysis of various rotational and loading conditions, charts were established for various conditions, giving the balance weights and their required location. Indication of balance or unbalance of the test enclosure is accomplished by the use of Baldwin-Lima-Hamilton Company strain gage type torque pickups. Torque fluctuations or balance are indicated on meters located on the control desk.

The yoke supports the test enclosure and is "U-" shaped of welded steel construction. It is mounted vertically and can rotate in either direction. Attached to the yoke is the pintle shaft which is an inherent part of the yoke supporting it. The pintle shaft is hollow to allow for a drive shaft which provides the rotation to a nonmetallic pinion gear which turns the ring gear of the test enclosure. The yoke assembly contains three slip ring stacks on the centerline of the horizontal axis of rotation of the test enclosure. These power, control, and physiological slip ring stacks enable circuitry to enter and exit from the test enclosure.

The pintle support structure is a pyramid shape welded steel unit which carries the pintle in two large bearings mounted therein. This structure in turn is mounted on reinforced concrete foundations on the building's main floor.

Both the horizontal axis of the test enclosure and the vertical axis pintle shaft contain slip ring stacks for the transmission of electrical power to and from the device test enclosure (see Fig. 6). These vertical axis slip ring assemblies are carried on the lower portion of the pintle shaft and its auxiliary shaft.

The "Power Slip Ring Stack" is composed of sixteen individual polished phosphor bronze rings.

The "Control Slip Ring Stack" is composed of ten individual silver surfaces laminated to bronze rings.

The "Physiological Slip Ring Stack" is composed of eight individual gold slip rings. Each individual slip ring is separated by a laminated phenolic insulating ring. Each slip ring is contacted by carbon brushes mounted in two flat-spring type brush assemblies. Each slip ring assembly rotates with the pintle shaft.

Rotation of the test enclosure, either horizontally or vertically, is accomplished by two drive unit assemblies. These drive unit assemblies are mounted on a welded

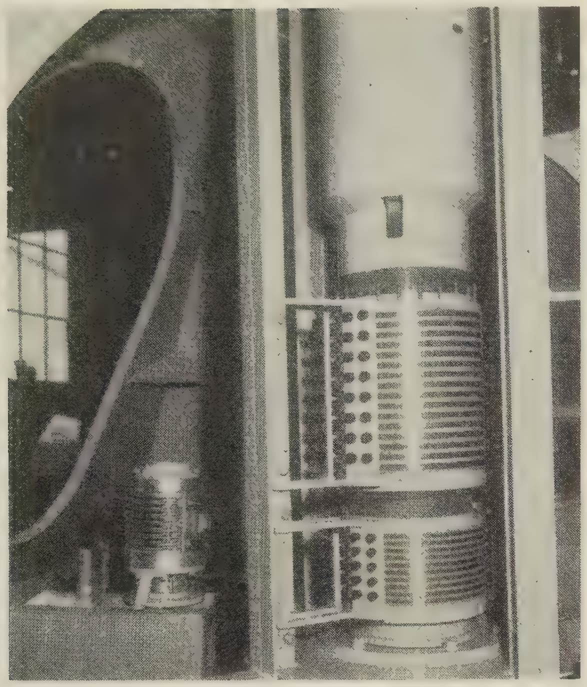

Fig. 6—The Human Disorientation Device; pintle and pintle support structure showing power, control, and physiological slip rings.

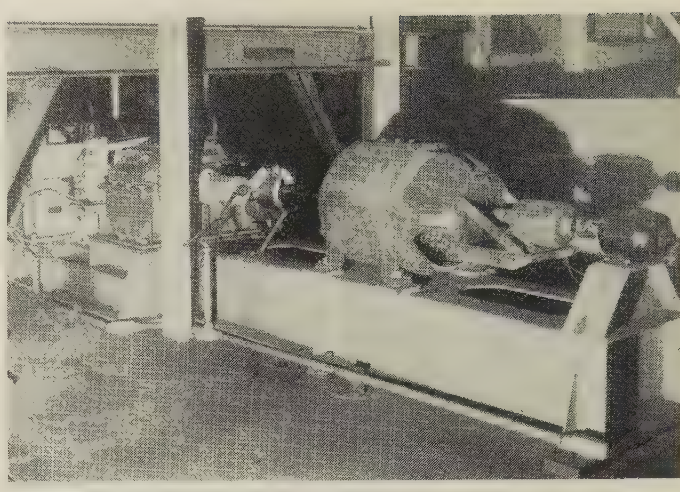

Fig. 7—The Human Disorientation Device—drive system; showing tachometer generators, dc drive motor, torquemeter, overspeed relay, two-speed gear box, friction brake, and duplex gear box.

steel base and are located at 90° to each other. Each drive unit (see Fig. 7) consists of a tachometer generator (speed control), another tachometer generator for indicating speed, a dc drive motor, a torque meter pick-up, a two-speed gear box, a friction brake, and an over-speed relay. Each of the drive unit assemblies feeds into a duplex gear box which rotates the yoke assembly about the vertical axis, and the test enclosure about the horizontal axis.

Each axis drives through a two-speed gear box, either in direct drive or at a 10:1 reduction. Change in speed range is accomplished by changing the position of the shift lever on the gear box.

The two-speed gear box contains, for each drive unit, centrifugal-type relays set to stop the device if the speed exceeds the pre-set, predetermined safe values.

The gear boxes and main bearings in the pintle system are lubricated through a forced feed-pump system.

The device's electrical drive and control system (Figs. 8 and 9) was designed and constructed by the General Electric Company, Waynesboro, Va.

One main motor generator set consists of a fully compensated 3600 rpm dc generator to supply power to the main dc drive motors and a 100 hp 3600 rpm, 440 volt, three-phase, 60-cycle squirrel-cage induction motor. Included in the motor generator set is a fly wheel which minimizes line transients during peak loads. The other main motor generator set is similar, except that the drive motor is rated at 30 hp.

The first-stage motor generator sets are induction motor driven and supply the excitation for the main dc generators.

The main drive motors consist of a 36 hp, 1800 rpm, 435 volt, dc open, 40°C rise, drip-proof, fully-compensated, shunt-wound drive motor with the capability of momentary load peak of 280 hp.

The main magnetic and electrical panels for controlling the electrical drive motor and generator circuits are located in three floor mounted cabinets. The amplidynes which provide the excitation for the main dc drive motors are located in these panels.

Regenerative braking is controlled by the manually-operated speed-controlling helipots with the degree of braking a function of the rate at which the potentiometer rotation is decreasing.

Dynamic braking with spring applied friction braking is used to stop the drive equipment. Upon actuation of the device's stop-button, the main dc loop contactor will drop out, closing the motor armature across the braking resistor. The friction brake is actuated after a given time delay.

Complete control of the rotation of the device test enclosure is accomplished from the control-desk (Fig. 10), which is located in such a position that the operator has a full view of the test enclosure. The operator controls the starting, stopping, velocity, and acceleration, either manually or automatically, of any program within the scope of the device. Indications of velocity, acceleration, torque, and position of the test enclosure are furnished at the control-desk as instrument indications. An emergency stop button is located at the center of the desk. The control-desk also contains "JOG" push buttons for intermittent rotation of the test enclosure in either the horizontal or vertical axis of rotation. The "JOG" control allows for the positioning of the enclosure before or after a controlled run is accomplished.

The calibrating console incorporates a light beam galvanometer, precision potentiometer, standard cell, volt box, wet-cell battery and battery chargers. This

Fig. 8—The Human Disorientation Device—first floor of building showing main mg sets, first stage mg sets, main control panels, dynamic braking resistors.

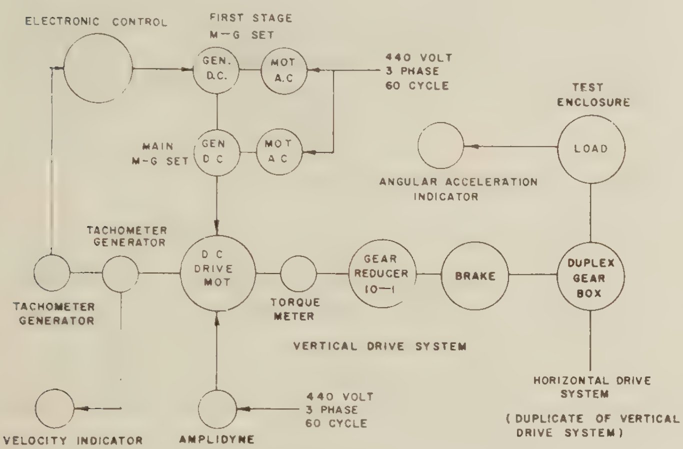

Fig. 9—Electrical and mechanical drive system of Human Disorientation Device.

calibrating equipment allows for the accurate setting and calibration of control voltages.

The patch panel console enables control and power circuits to be patched into the proper test enclosure outlets as appropriate. The patch panel also allows the various recording equipment to be patched into the output recording circuits of the device. The console contains the following:

1) A control circuits panel which provides receptacles for remotely controlling test apparatus within the test enclosure. This panel contains seven female cannon plug connectors.

2) A power circuits panel which provides power to panels within the test enclosure. This panel contains twenty-six female cannon plug connectors. Test enclosure interior light control and dimming, and 110 volts ac "regulated" and "unregulated" power are incorporated.

3) A physiological recording panel which provides eight female cannon plug connectors for the attachment of various medical instrumentation and recorders.

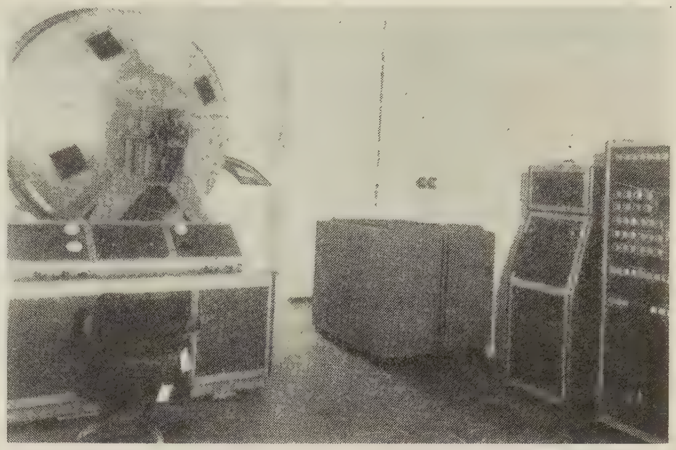

Fig. 10—The Human Disorientation Device—second floor of building showing control-desk, automatic programmer, calibrating console, patch panel console, and test enclosure.

4) A recording circuits panel which provides six female cannon plug connectors to enable the recording of velocity, acceleration, torque, and position.

5) Each patch panel contains one female Amphenol connector for complete parallel connection of the circuits.

A curve follower type program generator is provided for automatic operation of the device and the control of angular acceleration. The program generator will follow an infinite number of acceleration curves for either axis or a combination of axes. The programmer is a modified Variplotter Model 205L of the type manufactured by Electronic Associates Incorporated of Long Branch, N. J. The unit was modified in the following manner:

1) A function generator package was added.
2) An amplifier package was added.
3) A pen interchange and lift circuits were removed.
4) A network panel was added.

Acceleration curves for horizontal and vertical axes are made on drawing or graph paper, using silver conducting ink. With the curve paper on the programmer, the curve follower oscillator produces a voltage to the curves. The curve follower head follows the acceleration curves as the arms cross the board at a constant rate. The curve follower head enables the pick-up brush in each plotting arm to furnish the integrating amplifier with a voltage signal. Each amplifier then furnishes an output to the control system of the horizontal and vertical axes of the device.

The curve following surface is 30 inches square. The Variplotter operates on single phase, 120 volt, 60-cycle current. Input rating is approximately 700 watts.

Measurement of angular acceleration is accomplished by the use of four angular accelerometers. Two of the accelerometers are mounted on the horiozntal axis of the test enclosure: one measures between 0.1° per second squared and 30° per second squared, the other measures between 1° per second squared and 300°

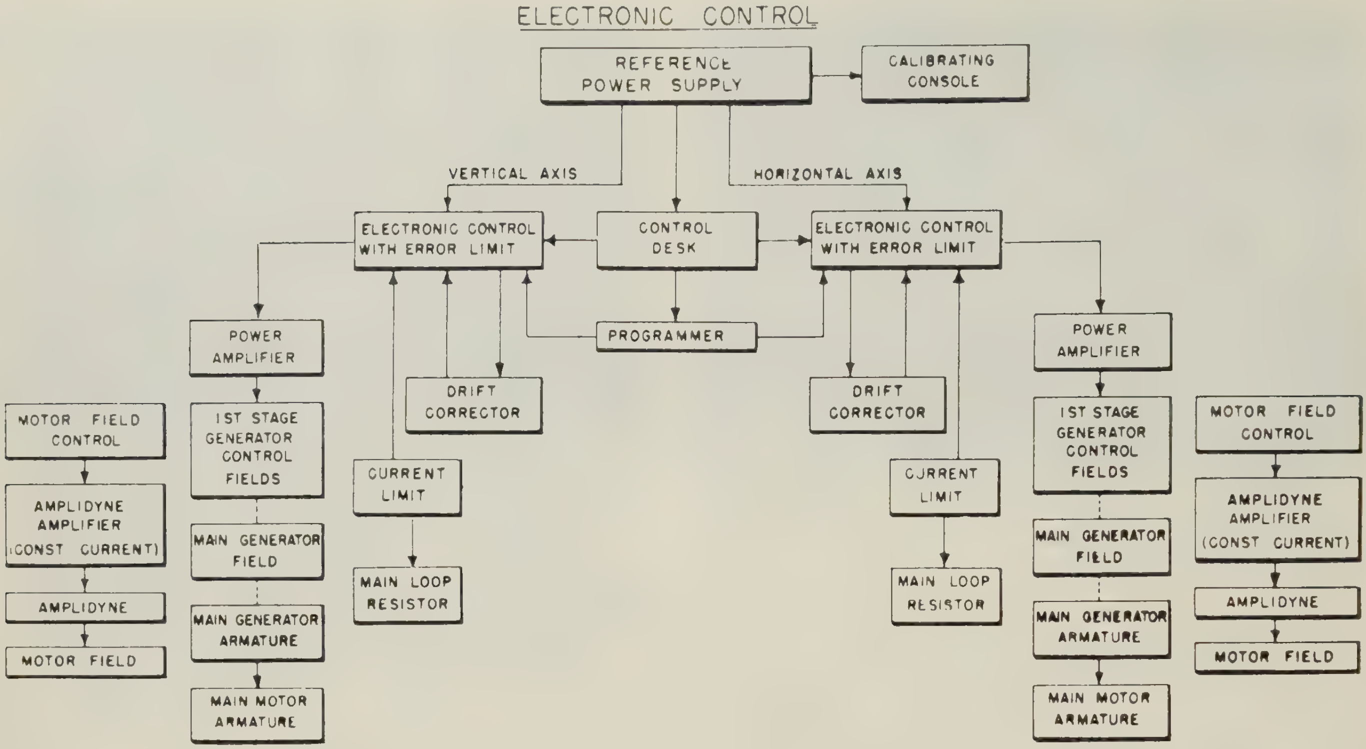

Fig. 11—Electronic control and drive system of the Human Disorientation Device.

per second squared. The other two accelerometers are mounted on the yoke of the device and measure the angular acceleration in the same ranges about the vertical axis.

Through the use of the curve follower type programmer, a variable dc voltage output is furnished by each of the two acceleration curve followers. The output is then integrated electronically by a four-amplifier unit to produce an electrical output proportional to velocity. This output is then furnished to the control and drive system of the device.

Movement of two curve follower heads produces a dc voltage output which is electronically integrated by two amplifiers and directed to the electrical drive of the device. The third amplifier drives each programmer arm at pre-selected speeds, by means of a ramp function, while the fourth amplifier furnishes the curve follower programmer with an accurate reference power supply. The automatic programming of angular acceleration can be varied from 3 seconds to 30 minutes total time.

Electronic control of the device is accomplished as shown in Fig. 11. The Electronic Control and Error Limit Circuitry is contained in the three main control panels, one for the vertical axis drive, one for the horizontal axis drive, and one for combined drive circuitry.

Starters for the dc motor amplidynes, the first-stage mg sets, and the main mg sets are incorporated in the main control panels.

The calibrating console enables the accurate setting of the reference power supply voltages and the calibration of same.

The reference power supply establishes and furnishes to the electronic control-panels the required reference voltages.

The amplidyne and amplidyne electronic amplifier provides the regulated field and constant current to the main dc drive motors.

The current limit circuitry enables the limiting of the current in the main loop circuits in both speed ranges of the device.

The error limit circuits of the electronic control-panel obtain the error signal by comparing the input and feedback circuits. The tachometer generators connected to the main dc drive motors furnishes the feedback signal for comparison with the input.

The drift corrector enables the error signal to be converted to a square-wave dc signal which is amplified and furnished to the cathode of the cathode follower tube. Drift in the amplifier or input circuitry is minimized in this manner.

The power amplifier circuits are furnished to the amplified reference error signals which in turn control the power amplifier tubes and buck or boost the first stage generator fields, thus enabling the main drive motors to be controlled.

It is expected that the Human Disorientation Device will permit a wide range of physiological investigations into the human reaction and capability in space flight.

The equipment is designed so that the device's control capabilities can be modernized to encompass additional simulation requirements, resulting from advanced knowledge in the dynamic area of human physiology.

A Land-Mass Radar Simulator Incorporating Ground and Contour Mapping and Terrain Avoidance Modes*

W. P. JAMESON† AND R. M. EISENBERG†

Summary—**This paper describes a method of simulating the radar displays of an airborne radar system. The simulator employs a scan-programmed vidicon tube and a low-power light source in conjunction with a three-dimensional terrain model to simulate radar return from land-mass formations, cultural areas, and target complexes. All effects of a moving aircraft, including velocity, heading, altitude, position, and attitude, are included in the simulation.**

This device will produce the displays for ground mapping, contour mapping and terrain clearance radar systems. It may be employed with an operational flight simulator or as a self-contained radar mission trainer for radar navigation and blind bombing operations.

Introduction

DURING World War II, the need for simulation of airborne radar systems for training purposes was recognized. Through the ensuing years the programs initiated to develop radar simulation techniques have resulted in the creation of several acceptable systems.

As the development of radar systems has advanced, many of these techniques have been taxed beyond their capabilities and have failed to keep abreast of the actual system design. Thus the stimulus is provided for launching new programs to arrive at a reasonable solution to the many problems encountered in the simulation of complex, high performance radar systems.

Increasingly heavy emphasis is being placed upon "high-fidelity" radar simulation because of the problems encountered in the training of a radar operator with actual equipment. Aside from the expense of operating an airborne system under actual conditions, the problem is one of training an operator to perform many tasks efficiently. This is particularly true of the pilot of a single place fighter-bomber aircraft who must perform the duties of a pilot, navigator, radar operator, radio operator, and bombardier during the course of a single mission. An operational flight simulator for any size aircraft must teach the pilot or crew to perform all these tasks in an efficient manner and teach him to interpret the information presented by the radar system and automatic navigation systems accurately and rapidly. In a sense it should be possible for a pilot and crew to "pre-fly" an actual mission to help assure the success of an operation.

Radar Simulation Techniques

Many systems using various techniques have been produced to simulate ground surveillance radar sets. The following is a brief description of some of these devices:

Ultrasonic

This is an extensively used technique utilizing the propagation of ultrasonic waves in water. The simulated radar reflection pattern is produced by the sound waves reflected from the surfaces of a three-dimensional terrain model mounted on the bottom of a shallow tank of water. The transducer and pickup are positioned to simulate the aircraft position over the area of interest.

The water must be carefully filtered and purified to keep it free from foreign matter. The temperature must be maintained at a specific level to assure a constant propagation velocity.

The propagation velocity of sound in water at a given temperature and the propagation velocity of electromagnetic waves in space are physical constants which allow a direct, fixed analogy to be established. The resultant scale ratio for the terrain model is 210,000 to one. The ultrasonic system is limited to this scale ratio where the indicator sweeps cannot be changed. Range resolution is poor at short ranges due to severe interference effects, therefore limiting the low altitude simulation capability. Many of these problems could be solved, but the limited scale ratios and the space requirements for this system make it unattractive for development as a simulator for today's high performance radar systems.

Pre-Programmed Tape or Film Strip

Actual video signals in a radar receiver may be recorded on tape or film during an actual flight, then played back in a device which will produce the indicator displays. This method is seriously limited since no variables may be introduced into the problem while maintaining the validity of the radar information. The simulation is accurate for one preselected flight path. Such a device may be useful in premission briefing to familiarize a radar observer with the radar pattern of a particular target complex, but could not be used successfully as an operational radar simulator.

Matched Photoplate

The matched photoplate has one great advantage over all systems devised to date. This advantage lies in its ability to store huge land-mass areas in a small space. Two photoplates are used to accomplish the information storage. One plate contains terrain elevation information, the other stores the reflectivity (at one altitude) information. This pair of plates is scanned synchronously by two similar light-optical systems. Television camera type tubes are used to convert the light variations into electrical signals which are then used to create the radar

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† Nuclear Products-Erco Division of ACF Industries, Inc., Riverdale, Md.

indicator displays. Shadow effects are produced synthetically by a computer receiving the terrain elevation video and terrain reflectivity video as inputs.

Scale ratios of three million or four million to one may be used. Thus large areas of the earth's surface may be represented on two relatively small photoplates. There are several disadvantages which exist at present. These include heating problems due to the high intensity light sources, optical alignment problems, some of which arise from the large scale ratios, poor integration of elevation and cardinal effects in regard to aspect vs radar reflectivity, and poor low altitude simulation.

Light Reflective Systems

Many of the systems being developed and in use as simulators for the higher performance radar sets are classed as light reflective systems. This general class of systems achieves a good balance between performance, accuracy of simulation, simplicity, durability, and flexibility. The system to be described in the following sections of this paper is classed as a light reflective system.

All have in common the method of land-mass storage. Their differences lie mainly in the means used for propagation of the light and converting the reflected light patterns to video signals.

A three-dimensional terrain model is mounted on a flat bed or frame. The model is cast or formed of a plastic material. Cultural areas and target complexes are painted on the map surface as a pattern of spotted gray areas or may be cast in relief as blocks of plastic painted the proper color or gray shade corresponding to the radar reflectivity of the object or objects. Water appears as a glossy black surface while land areas are painted a flat gray or are textured with fine grit to yield the desired reflective properties.

A gantry mechanism carrying the light optical devices rides over the map with the light source or light pickup device having a position corresponding to the simulated airborne radar position. The carriage supplies horizontal motion and a portion of the light optical system is moved vertically to simulate altitude.

The light may be propagated in a shaped high intensity beam which scans the map surface in accordance with the simulated radar antenna scan program. Another technique utilizes a flying spot-scanner light source for light programming. The light pickup, analogous to the radar receiver, receives the light reflected from the map surfaces, and the resultant video signals are used to modulate the intensity of the indicator sweeps to produce the radar display. This paper describes a technique utilizing a scan programmed light pickup with a light source which floods a specified map surface area.

A wide range of scale ratios may be used with these techniques. There are no great problems encountered in handling the propagation medium. The life of the scanning components is relatively high. The range resolution and low altitude simulation capabilities are limited only by the photoelectric devices utilized and the terrain model. Techniques for producing highly accurate terrain models are well known. Methods whereby the models may be modified and kept current have been developed and are being improved. These models may be constructed to be compatible with a given simulation technique so as to produce many of the desirable radar effects not possible with other land-mass storage means. The scale ratios which may be used with these systems in the present state of development are not as high as those attainable with a matched photoplate, but it is believed that the many desirable features of some of these light reflective systems make them the most attractive for use in the radar simulation field at the present time.

Description of the Scan Programmed Vidicon Technique

The system described herein is capable of simulating three modes of operation of a radar system. These three modes are Ground Mapping, Contour Mapping, and Terrain Avoidance (or Terrain Clearance). Fig. 1 is a block diagram of the system configuration for simulating the ground mapping mode of operation.

Ground Mapping Simulation

General Description: An assembly consisting of a light source, prism, and light pickup device is mounted on a gantry arranged so that the assembly can be positioned in X and Y coordinates over a three-dimensional terrain model in accordance with signals representing the position of the simulated radar carrying aircraft. The assembly is capable of being rotated, in accordance with the simulated aircraft heading, about a pivot point located near the center rear edge of the prism as shown in Figs. 1 and 2. The light source is provided with a vertical drive to enable its altitude above the terrain model datum plane to be varied in accordance with altitude signals. The X-Y position of light source relative to the prism is fixed. The front of the light source is at the previously mentioned assembly pivot center line. The light beam emanating from the light source is shaped so as to evenly illuminate a scaled area on the map surface equal to, or greater than, the azimuth and range search area of the radar being simulated. A representative area of illumination is indicated in Fig. 3.

As indicated in Fig. 1, the area of interest, *i.e.*, the area to be presented on the simulated radar indicator, is focused by the lens of the camera onto the photocathode of a vidicon camera tube. The photo-cathode is commutated by the electron beam in the vidicon which is deflected in accordance with a PPI sector scan program. The scanning pattern on the vidicon faceplate is indicated in Fig. 4 which also depicts an A scan presentation of the video output from the vidicon for the azimuth position indicated. The low level video signals obtained from the camera tube are amplified by means of suitable video amplifiers, clamped to a reference level, and

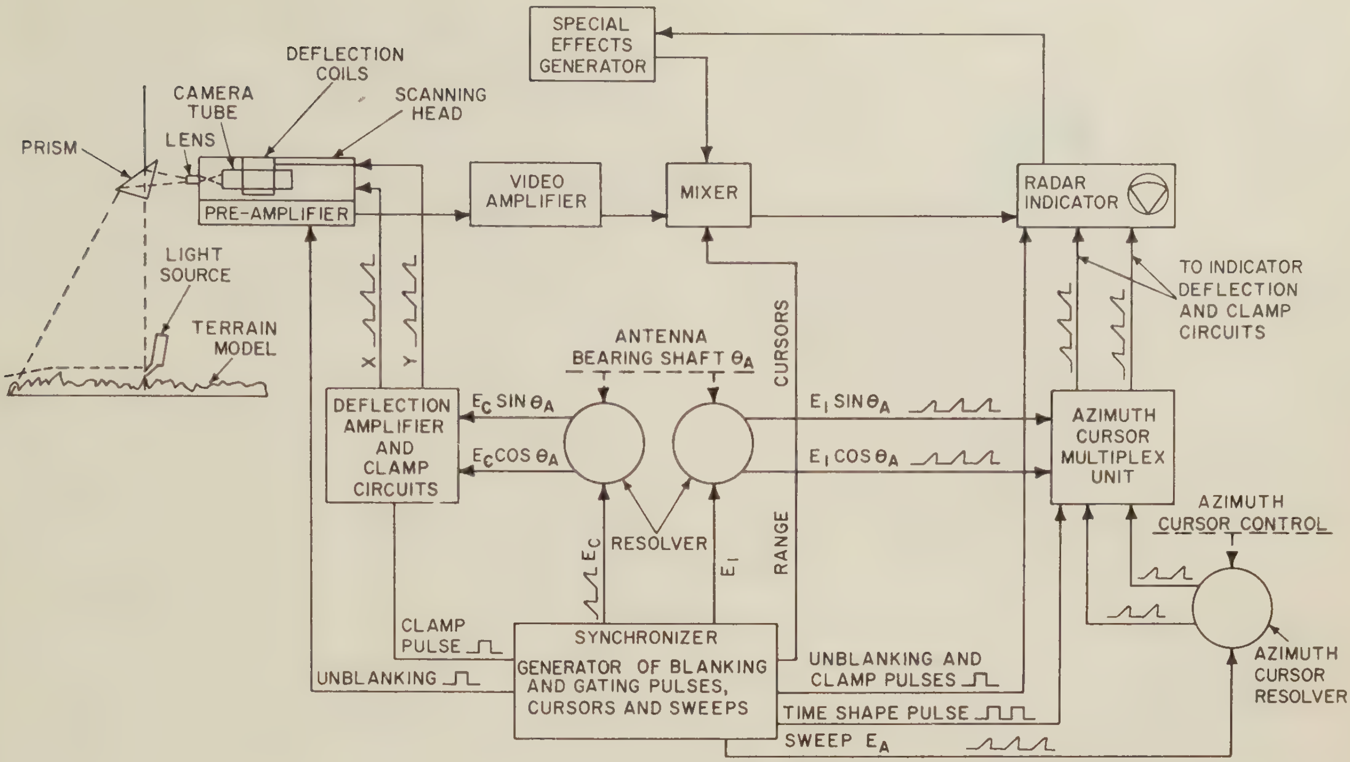
SPECIAL EFFECTS GENERATOR
DEFLECTION COILS
CAMERA TUBE
SCANNING HEAD
PRISM
LENS
PRE-AMPLIFIER
VIDEO AMPLIFIER
MIXER
RADAR INDICATOR
LIGHT SOURCE
TERRAIN MODEL
X
Y
CURSORS
TO INDICATOR DEFLECTION AND CLAMP CIRCUITS
ANTENNA BEARING SHAFT θA
DEFLECTION AMPLIFIER AND CLAMP CIRCUITS
EC SIN θA
EC COS θA
E1 SINθA
E1 COS θA
AZIMUTH CURSOR MULTIPLEX UNIT
RESOLVER
EC
E1
RANGE
AZIMUTH CURSOR CONTROL
CLAMP PULSE
SYNCHRONIZER
GENERATOR OF BLANKING AND GATING PULSES, CURSORS AND SWEEPS
UNBLANKING
UNBLANKING AND CLAMP PULSES
TIME SHAPE PULSE
SWEEP EA
AZIMUTH CURSOR RESOLVER

Fig. 1.

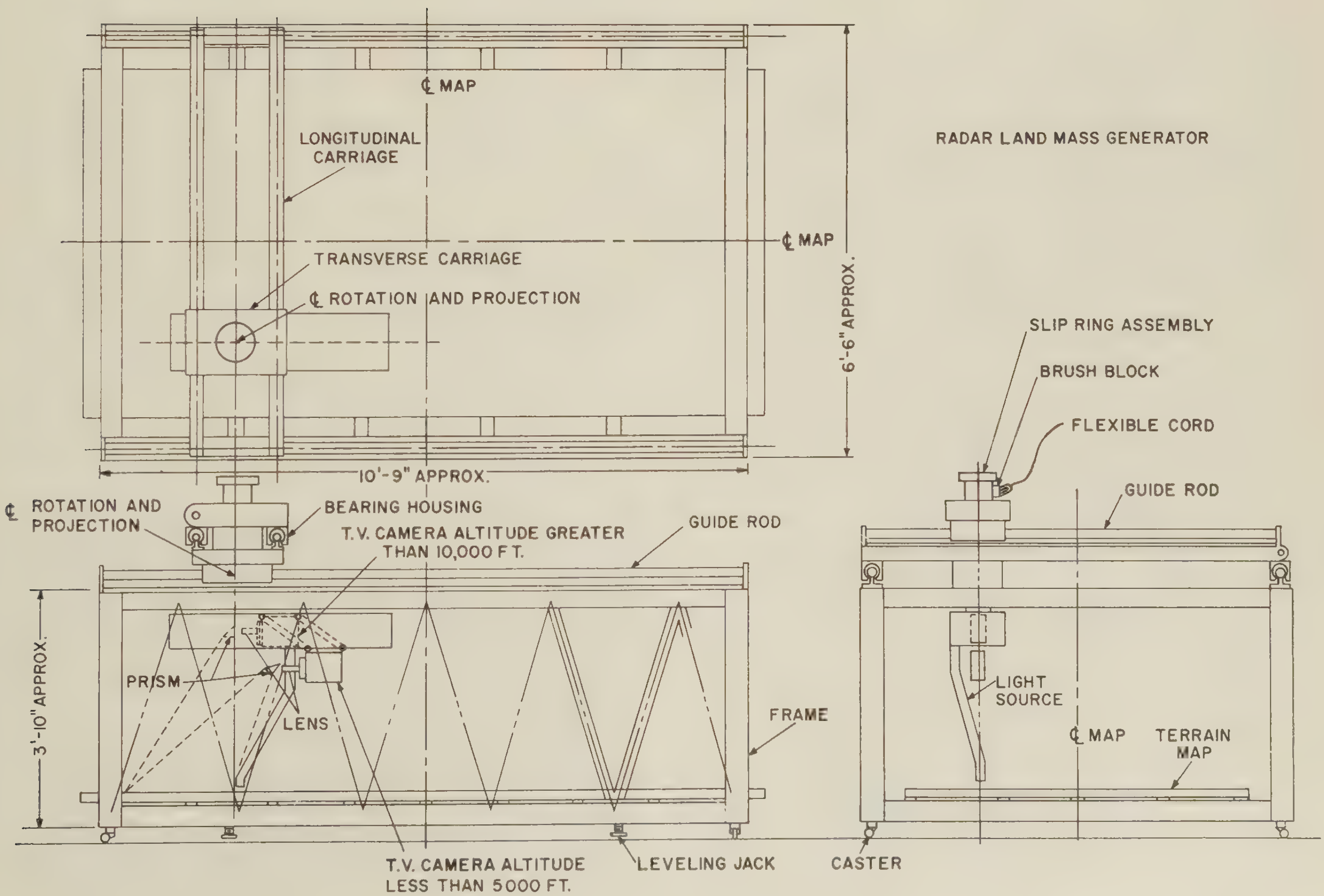
RADAR LAND MASS GENERATOR
℄ MAP
LONGITUDINAL CARRIAGE
℄ MAP
TRANSVERSE CARRIAGE
℄ ROTATION AND PROJECTION
6'-6" APPROX.
10'-9" APPROX.
℄ ROTATION AND PROJECTION
BEARING HOUSING
T.V. CAMERA ALTITUDE GREATER THAN 10,000 FT.
GUIDE ROD
3'-10" APPROX.
PRISM
LENS
FRAME
T.V. CAMERA ALTITUDE LESS THAN 5000 FT.
LEVELING JACK
CASTER
SLIP RING ASSEMBLY
BRUSH BLOCK
FLEXIBLE CORD
GUIDE ROD
LIGHT SOURCE
℄ MAP
TERRAIN MAP

Fig. 2.

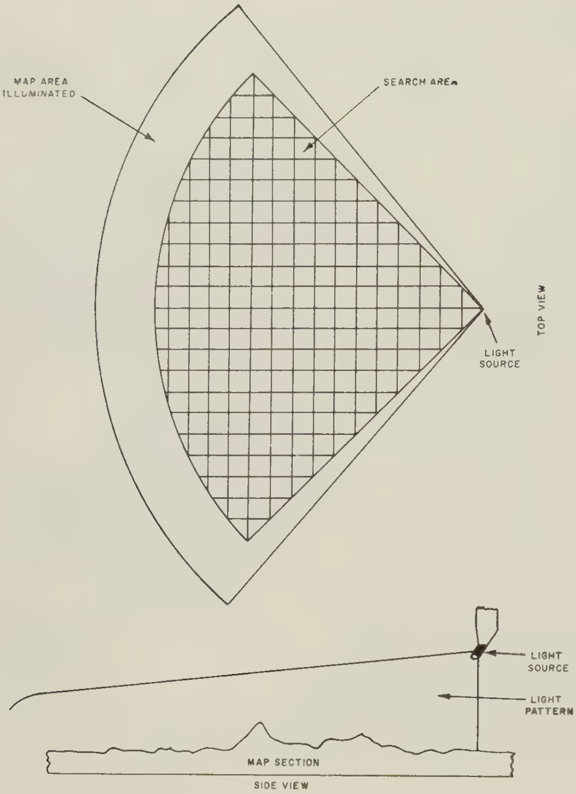

Fig. 3—Terrain model illumination.

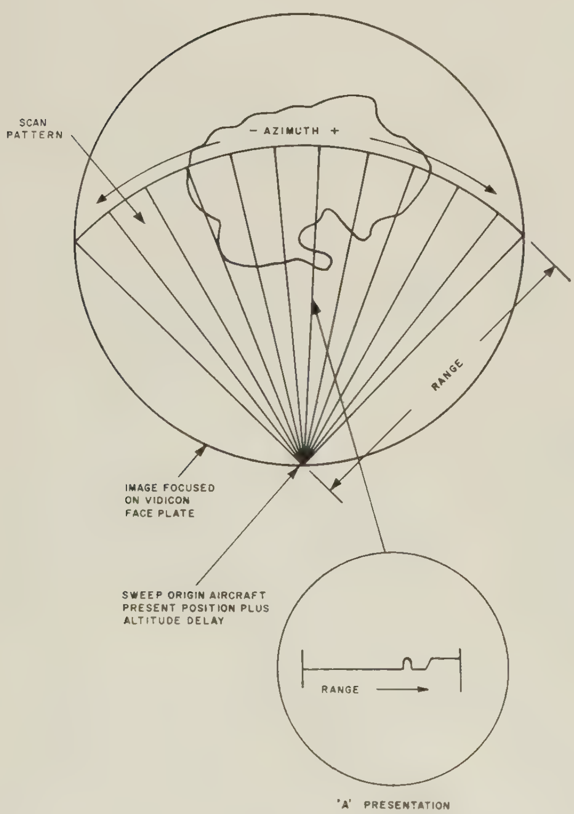

Fig. 4.

applied to the grid or cathode of the radar indicator tube. The PPI scan is generated by resolving a sweep of suitable waveform into its X and Y components about the azimuth bearing representing the aircraft heading.

A similar scanning system is utilized to sweep the radar indicator tube screen in synchronism with the vidicon sweep. The video signals applied to the radar indicator CRT cause intensification of the trace at the correct position thereby painting on the indicator the image present on the photo-conductive faceplate of the vidicon.

With a terrain model constructed according to radar return prediction data, the presentation on the radar indicator is an accurate simulation of the presentation that would be observed on an actual airborne radar set over the terrain. Although a PPI sector display is described here, this is not meant to infer that this is the only type of display which may be simulated with this technique. Any type of scan utilized by search radar systems is applicable to this system.

The sweeps, gating pulses, unblanking and clamping pulses, and range marks are generated in a synchronizer unit. The design of the circuits in this synchronizer may be arranged to accommodate various pulse repetition rates, range mark spacing, altitude delay circuits, and sweep expansion circuits so that any radar set performance may be accurately simulated. Fig. 5 is a simplified block diagram of typical synchronizer and vidicon sweep circuits for the simulation of a ground mapping radar system including distance mark generation and range cursor generation.

Various effects such as jamming, noise, or the addition of electronically-generated air targets are introduced into the system by means of the video mixer as indicated in Fig. 1.

Simulation of Changes in Range Coverage: Changes in range coverage (an operator selected function) are effected by changes in the lens field of view. The lenses are mounted in a turret on the camera. The turret is remotely switched from the range selection control on the radar operator's set control. A wide angle lens is used for the longest range coverage. When shorter range operation is selected, a lens with a narrower field of view is positioned in optical alignment with the vidicon and prism. Since the field of view is narrowed concentrically, the prism must be tilted slightly about its lateral axis to return the rearmost edge of the field of view to the zero ground range point. Fig. 6 shows the field of view of two lenses and demonstrates the rearward shift necessary to accomplish the scanning pattern compensation.

The Light Source: The light source used with this technique consists of a lamp and housing, a collimating optical assembly, and a "light pipe." The lamp is a relatively low power incandescent bulb. The light pipe is constructed of a lucite plastic rod $\frac{1}{8}$ inch in diameter.

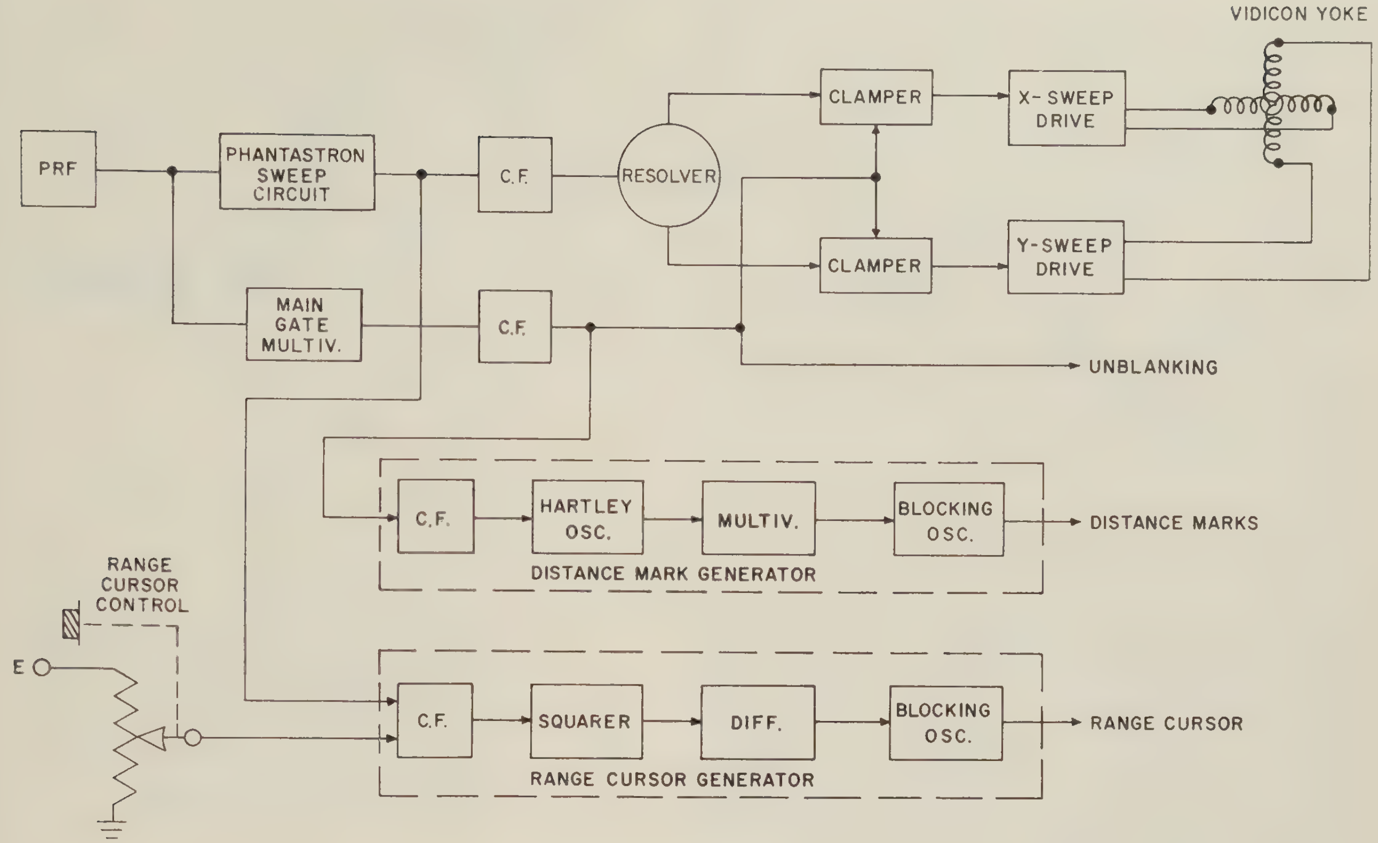

Fig. 5.

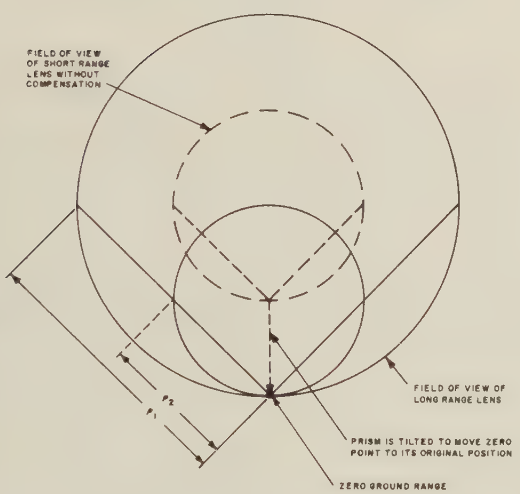

Fig. 6—Field of view compensation for range coverage lenses. P_1 = range of coverage of wide angle (long range) lens. P_2 = range of coverage of narrow angle (short range) lens.

This lucite rod is shaped at its lower end to disperse the light in the pattern indicated in Fig. 3. This approach was used to allow the light source to travel in depressions in the terrain model surface, thereby enhancing the low altitude simulation. A low-power light may be used as a source for two reasons. First, this technique does not depend upon a programmed light beam with its many optical elements. The light losses do not necessitate a high intensity lamp to transmit the necessary light through multiple optical interfaces to the map surface. Second, the vidicon tube possesses excellent photosensitivity. Some of the vidicons now in production are capable of producing satisfactory video signals with as little as 0.2 foot-candles of illumination on the faceplate of the tube. The heating problems attendant to high intensity shaped beam sources are thereby eliminated allowing the light source to travel in close proximity to the map surfaces without danger of causing damage to the plastic material. Since the light source will be very close to the surfaces during low altitude operation, a means of preventing physical damage due to a collision with the map is provided. Fig. 7 is a sketch of a portion of the light source showing the collision switch constructed as an integral part of the light source assembly. The lucite rod passes through a rubber grommet at the upper end of its support housing. At the lower end of this support housing, a ring of metal feelers, similar to finger stock material, is fastened so as to just clear the lucite rod. At this point on the lucite rod a metal band is fastened and connected to a collision relay circuit through appropriate wiring. A wire connected to the metal feelers completes the circuit should the lucite rod bend and touch the feelers. This will occur if the lower end of the

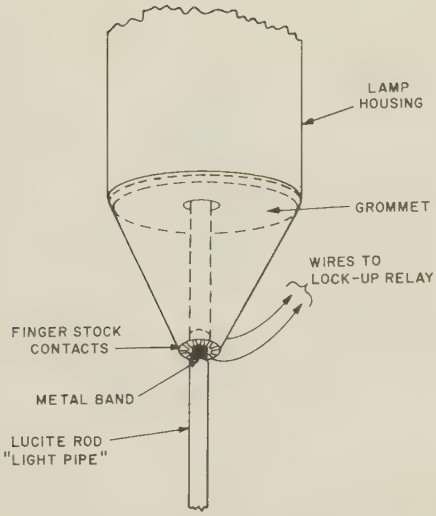

Fig. 7—Light source collision switch.

rod strikes the map surface with a force greater than approximately 5 grams. Actuation of the collision relay will lock the horizontal and vertical drive servos and require that the light source be slewed upward before the servos can be reactivated. When the radar simulator is used as a part of an operational flight simulator, this collision signal may be used to energize the crash system indicating a collision with the earth's surface.

Map Construction: The map is constructed of a plastic material and cast from a master mold. The target complexes are stored in relief with blocks of the map material representing targets and groups of targets. Water is represented by a glossy black surface. A class "one" or highly reflective target is painted a flat white on the faces of the target blocks. Three shades of gray are used to represent targets of lower reflectivity classification and terrain. Texturing is used where applicable to create rough surface terrain reflectivity. The resultant model is a three-dimensional radar prediction map of a portion of the earth's surface. Target complex areas are constructed as inserts so that they may be removed and replaced by modified target areas. Small changes may be made on the model's surface by hand if the proper tools are used. The target complex inserts are faired into the surrounding map contours so that the line of demarkation is not visible to the camera. The entire map is braced on its under side so as to prevent sagging. A map of this type measuring 11 feet by 5 feet, with necessary integral bracing and mounting provisions, weighs approximately 200 pounds. Indexing marks are provided on the edge of the map with an alignment pin mounted in the exact center of the map base to mate with a bushing in the map bed.

Target Storage and Effects: The storage of targets (in relief) aids in the creation of proper target aspect, cardinal effects, and shadowing. A target having a low magnitude radar return with a high angle of incidence may, at low angles, become an outstanding or "class one" return. The construction of such a target type is indicated in Figs. 8(a)–(c).

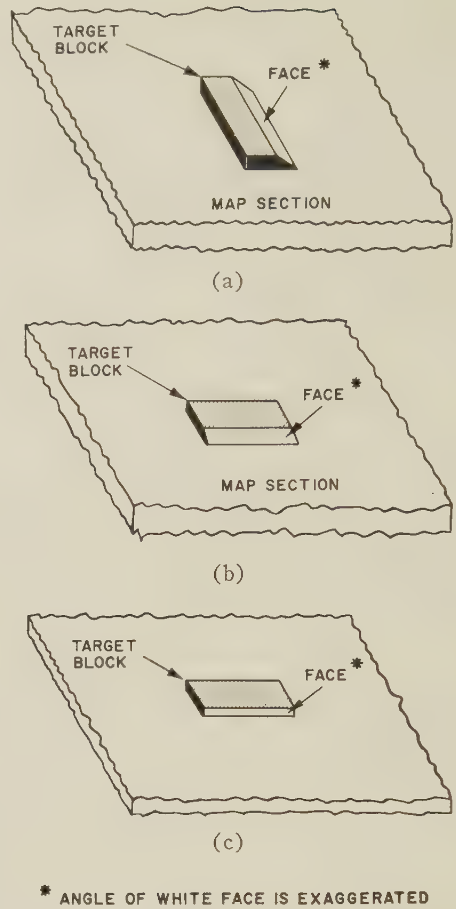

Fig. 8.

Fig. 8(a) is a low altitude, rear corner view of a faceted target block. Fig. 8(b) is a high altitude, frontal approach view of the target, and Fig. 8(c) is a low altitude, frontal approach view. The front face of the block is painted white. This type of target will produce excellent cardinal effects. That is, a return will be observed only when approaching the target from the proper direction. Groups of these target blocks representing a target complex will create a reflectivity pattern which will vary as a function of approach bearing.

Low Altitude Simulation: Further examination of Fig. 8 will indicate that the angle of the target facet can be varied so as to produce "no show" effects at high angles with good return at low angles or vice versa.

When the simulated aircraft is at high altitudes, the camera and prism are oriented as shown in Fig. 9(a). The view then is essentially perpendicular to the map surface, and the vertical sides of the target blocks are not seen by the camera. At lower altitudes, the prism is rotated to decrease the angle of incidence as shown in Fig. 9(c). In order to continue observing the same map area, the camera is moved back as the prism is rotated

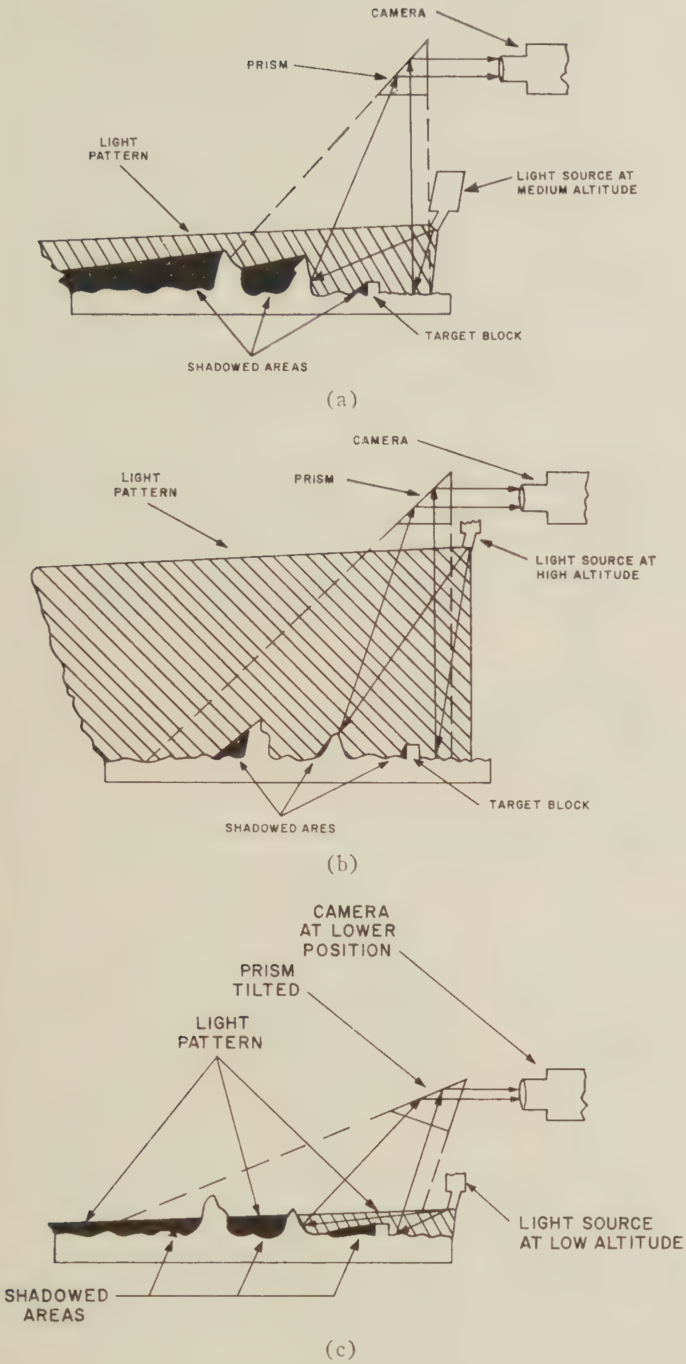

Fig. 9—(a) Shadow effect at simulated medium altitude; (b) shadow effect at simulated high altitude; (c) shadow effect of simulated low altitude.

so as to maintain the same map area focused on the photocathode. Since the aforementioned action would result in a larger area being observed, the camera is lowered so as to maintain the same field of view. The motion of the entire assembly is accomplished smoothly as a function of altitude. At altitudes above 10,000 to 15,000 feet (the exact altitude depends upon the map scaling and system geometry), the assembly is maintained at a fixed height above the model's datum plane. As the simulated aircraft descends through this upper altitude limit a servo motor begins moving the assembly down and aft. The lower limit of the assembly motion is reached as the aircraft descends through the lower altitude limit (2000 to 500 feet depending upon the lens field of view and the system geometry). At any flight altitude below this limit the assembly remains fixed in its lower position. Note that the light source does not move with the camera and prism assembly but continues to servo to a position simulating the aircraft's altitude. This camera assembly motion is an auxiliary motion used to create good low altitude simulation.

Shadowing Effects: Shadowing effects are realistically produced as the light source is raised and lowered as a function of simulated altitude, as indicated by Fig. 9(a)–(c). The camera sees only the surfaces of the map which are illuminated. Therefore, the video output of targets and terrain is obtained only when they are not in the shadowed areas.

Range Resolution: The results of tests performed on this system have indicated a resolution capability of 800 lines. The scale range resolution while simulating a radar range of 80 nautical miles is then 608 feet. This approaches the ideal range resolution capability of an airborne ground mapping radar system with a pulse width of 1 NSCC. The range resolution of the simulator improves when shorter radar ranges are simulated.

Operational Flight Simulator Tie-In: When this radar simulation device is to be used as a portion of a flight and tactics simulation system, the gantry motion, light source motion, and the camera motion are programmed from the flight simulator's position, bearing and altitude computers where:

V_n = Aircraft horizontal velocity
ψ = Aircraft heading
ψ_m = Orientation of the map major axis
K = Scaling factor of the terrain model
$\dot{L}_O$ = Longitudinal carriage rate
$\dot{L}_A$ = Lateral carriage rate.

The longitudinal carriage motion is described by the expression $\dot{L}_O = V_n \cos(\psi - \psi_m)/K$. The lateral carriage motion is according to the expression $\dot{L}_A = V_n \sin(\psi - \psi_m)/K$. The vertical motion of the light source is according to the expression

$$\dot{L}_h = \frac{dh}{dt} \Big/ K$$

where

$\dot{L}_h$ = Rate of vertical motion of the light source
dh/dt = Rate of change of aircraft altitude
K = Scaling factor of the terrain model.

The turning rate $d\psi/dt$ computed for the simulated aircraft drives the camera, prism, and light source assemblies about their turning axes at the rate of turn of the simulated aircraft.

The radar set controls and indicator controls, with appearance and function identical to that of the actual radar system, are located in the simulator cockpit or simulated aircraft radar operator's station.

A plot of the simulated aircraft's track over the earth's surface is recorded during a "mission," thus allowing a post mission critique for training purposes.

Use As a Radar Display Interpretation Trainer: In addition to its use as an operational radar training device, this system may be installed so as to provide classroom training in the skill of reading and interpreting the displays of a radar system.

A repeat indicator may be provided for a remote location with the necessary set and indicator controls. A preprogrammed flight track will provide the carriage motions for the radar simulator. A group of radar operators or pilots may then be instructed in the display interpretations and the correlation of the data presented on the radar indicator with that presented on standard aeronautical charts or radar prediction charts.

It is conceivable that this device may also be utilized to prepare flight crews for actual operations over unfamiliar terrain.

Terrain Clearance and Contour Mapping Simulation

General Description of Actual Radar Operation: During the terrain clearance mode of operation of a radar system, a clearance plane parallel to the flight path of the aircraft is established by the operator at some altitude above or below the aircraft. Only the terrain protruding above the clearance plane is displayed on the radar indicator. This enables the pilot of an aircraft to adjust his let-down or climb-out flight path angle to assure his clearing the terrain by a predetermined altitude.

During the contour mapping mode of operation a clearance plane parallel to the earth plane is established by the operator at some altitude above or below the aircraft. As in the case of terrain clearance, only that terrain protruding above the clearance plane is displayed. This provides means for identifying check-points and for locating possible let-down areas on the terrain.

Terrain Avoidance Simulator Technique: The geometry of the terrain avoidance problem is shown in Fig. 10. Definitions of symbols are as follows:

h = aircraft altitude

h_e = vertical distance below projected aircraft flight path to projected clearance plane

h_c = altitude of projected clearance plane at a point directly below aircraft

h_{tr} = instantaneous altitude of projected clearance plane. h_{tr} decreases with range

h_{ta} = instantaneous vertical distance from projected clearance plane to a plane parallel to the datum plane at an altitude equal to h_c

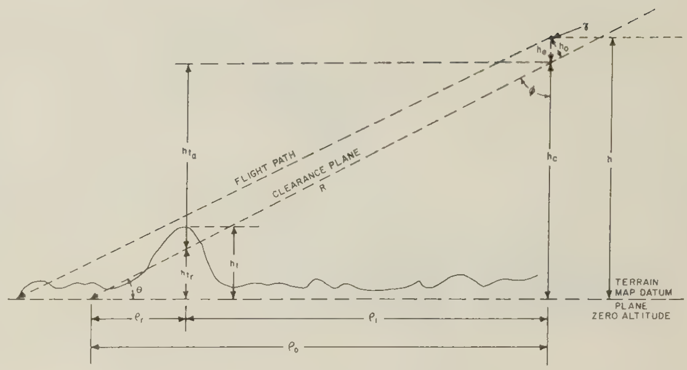

Fig. 10.

h_o = distance between flight path and clearance plane, pilot set

ρ_o = computed ground range from aircraft to intersection of clearance plane and zero altitude

ρ_i = instantaneous radar ground range (sweep voltage)

ρ_r = distance from ρ_o to ρ_i

θ = aircraft pitch angle

h_t = terrain altitude at distance ρ_i

$\gamma = \theta$.

Equations relative to the geometry of the problem are:

$$h_e = \frac{h_0}{\cos \gamma}$$

$$h_c = h\text{-}h_e$$

$$\rho_0 = \tan \phi h_c$$

$$h_{tr} = \tan \theta \rho_r$$

$$\rho_r = \rho_0 - \rho_i$$

$$\phi = -\theta + 90°$$

$$h_{ta} = \tan \theta \rho_i$$

$$h_{tr} = h_c - h_{ta}.$$

The equations solved in order to obtain a voltage proportional to the instantaneous altitude of the projected clearance plane (h_{tr}) are:

$$h_c = h - h_e$$

$$h_e = \frac{h_0}{\cos \gamma}$$

$$h_{ta} = \tan \theta \rho_i$$

$$h_{tr} = h_c - h_{ta}.$$

As shown in Fig. 11 the terrain altitude along the radar sweep must be determined. Special equipment, in addition to that utilized in the ground mapping mode, is used to accomplish this. Fig. 12 shows a method which uses a photo transparency whose emulsion density is inversely proportional to terrain altitude. The area of

this earth's surface represented by this transparency is identical to that of the area depicted by the terrain model in use for the ground mapping problem. A flying spot-scanner, positioned horizontally in synchronism with the camera, prism, and light source assembly on the terrain model gantry, and deflected in the same scan program as that of the vidicon tube, is mounted on one side of the transparency. A photomultiplier tube is positioned in the same manner on the opposite side of the transparency. The output of the photomultiplier for each sweep made by the flying spot is a waveform whose instantaneous amplitude at any point on the waveform is proportional to the terrain altitude at that same point in range on the map surface.

Fig. 13 shows a method whereby an opaque print and vidicon camera are used, in lieu of the transparency and flying spot-scanner, to derive the terrain altitude voltage. The terrain elevation information is stored on the print as varying shades of gray, the highest terrain being depicted by white and the lowest being depicted by black.

The contour video obtained by either of the two aforementioned means are compared to the voltage proportional to h_{tr}. Any video voltage having an amplitude greater than that of h_{tr} is squared and utilized to gate the video from the three-dimensional scanning head into the indicator video amplifier chain. During the terrain avoidance mode, the pickup head sweep is modified to display slant range.

Contour Mapping Simulator Technique: The geometry of the contour mapping problem is identical to that of terrain avoidance with the exception that the effects of pitch angle are eliminated. This establishes the clearance plane parallel to the ground plane, *i.e.*, $h_{tr}=h-h_o$.

Mounting of Additional Equipment: This additional equipment may be mounted in a number of ways, the choice of mounting being determined by the space available. The transparency or opaque print may be mounted under the terrain model bed or suspended above the terrain model carriages with the light source and pickup driven directly by the terrain model gantry. These auxiliary devices could also be mounted vertically on the side of the gantry or in a separate cabinet with servo drives for the light source and pickup devices receiving their inputs directly from the gantry servos.

The choice of either the transparency or opaque print techniques is dependent largely upon the space available. It will be noted from Figs. 12 and 13 that the transparency requires the use of devices mounted on either side of the plate while the opaque print need only have components on one side. The cost of either of these elevation storage media is a function of the scale ratios required with the larger scale ratio being the more expensive choice. Special data are not required to fabricate these plates or prints since existing terrain elevation data can be utilized.

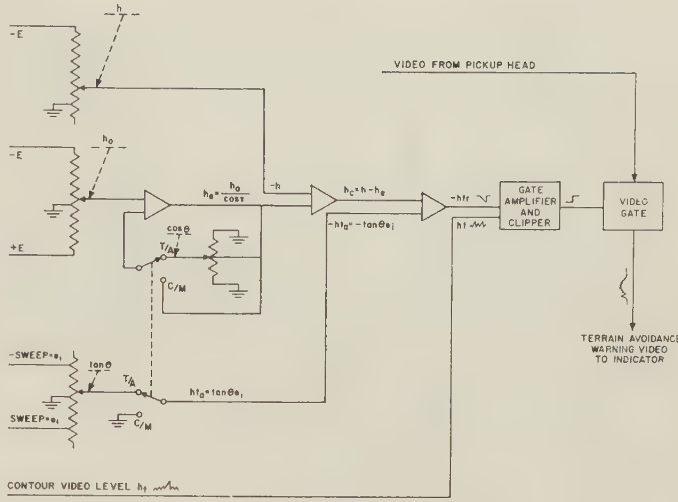

Fig. 11.

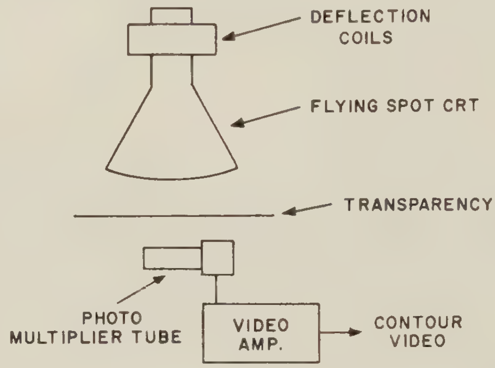

Fig. 12.

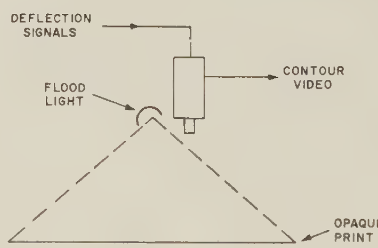

Fig. 13.

In operation the amplitude of the actual contour information voltage is compared to the preset clearance altitude signal, and when the contour information signal is greater than the desired clearance signal, the video from the terrain model camera is gated into the operator's radar indicator permitting this video to be displayed. By this means only the video from objects above the clearance plane are displayed to the operator.

Conclusion

The technique described in the preceding paragraphs provides a solution to many of the problems which have made other techniques unattractive.

The maintenance requirements of the system are kept to a minimum through the use of a noncritical propagation medium and a technique which does not require high intensity light sources with their attendant heat problems.

Reliability is attained through the utilization of proven pulse circuitry.

Fidelity of simulation of the radar presentation is made possible through the use of a high resolution, light sensitive device and methods to achieve good altitude effects, and a target aspect realism not available by other known means.

Flexibility is realized through providing a means for changing the target complex areas of a terrain model. Further, the entire map may be replaced and aligned rapidly to represent other known areas of interest. Modification for new radar characteristics is simply a matter of replacing those portions of the light source. sweep, and gating circuitry affected.

Acknowledgment

The authors wish to acknowledge the suggestions of Ross Gafvert of the Fighter Simulator Branch (WCLEQF), Aeronautical Accessories Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

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Thirty-Two Aircraft Radar Track Simulator*

L. PACKER†, M. RAPHAEL†, AND H. SAKS†

***Summary*—This paper describes a Radar Track Simulator which generates the track of thirty-two aircraft in x, y, and h coordinates accurate to one-hundreth of a mile and produces video accurate to one-hundreth of a mile in range, one milliradian in azimuth and two milliradians in elevation. The output video signals are modified by the radar beam pattern, aircraft scintillation noise, radar receiver noise, fading of video signal with range, and blip-scan effects to produce a realistic display.**

Introduction

THE track and radar simulator to be described generates the track of thirty-two aircraft in x, y, and h coordinates. Manual inputs determining the $\dot{x}$, $\dot{y}$, and $\dot{h}$ rates for these aircraft are converted from analog form to digital form by means of a central analog-to-digital converter. The digital $\dot{x}$, $\dot{y}$, and $\dot{h}$ numbers are integrated digitally and provide continuous information of the position of each of the aircraft. A continuous computation is performed to convert the x, y, and h numbers for the aircraft to ρ (range), sin β (elevation angle), and sin or cos of θ (bearing angle). Digital comparisons are then continuously made between the bearing angle of the aircraft and the antenna azimuth angle. Analog comparisons are made between the antenna elevation angle (of a three-coordinate radar) and the aircraft elevation angle. When the comparisons show that the aircraft is being illuminated by the simulated radar beam, the digitally-generated video pulses are gated through to the output sections of the equipment. Since the range is generated by the digital equipment, it is accurate to 0.01 mile in range up to a maximum of 500 nautical miles. The azimuth angle is accurate to one milliradian, except when the simulated radar has wide beamwidths (beamwidths larger than 8°). The elevation angle accuracy is two milliradians up to a maximum of 60°.

The gated video pulse is sent from the digital section of the equipment to the 64 output channels, 32 for the search and 32 for the height section. Aircraft scintillation noise as well as beam pattern and blip-scan information is used to operate on the video pulse. At this point, the video pulse has been converted to an RF signal having the proper amplitude and duration to correspond to the particular type radar being simulated. The outputs of the 32 search channels are mixed together at the simulated RF frequency, heterodyned, and then passed through an IF strip where the receiver noise is generated and the signal attenuation with range is accomplished. The IF strip output is detected and is fed to a PPI or other equipment having similar signal inputs. A similar radar receiver section is also provided for the three-coordinate radar.

Twelve of the input targets are controlled by the Target Control Unit to be described later in this paper.

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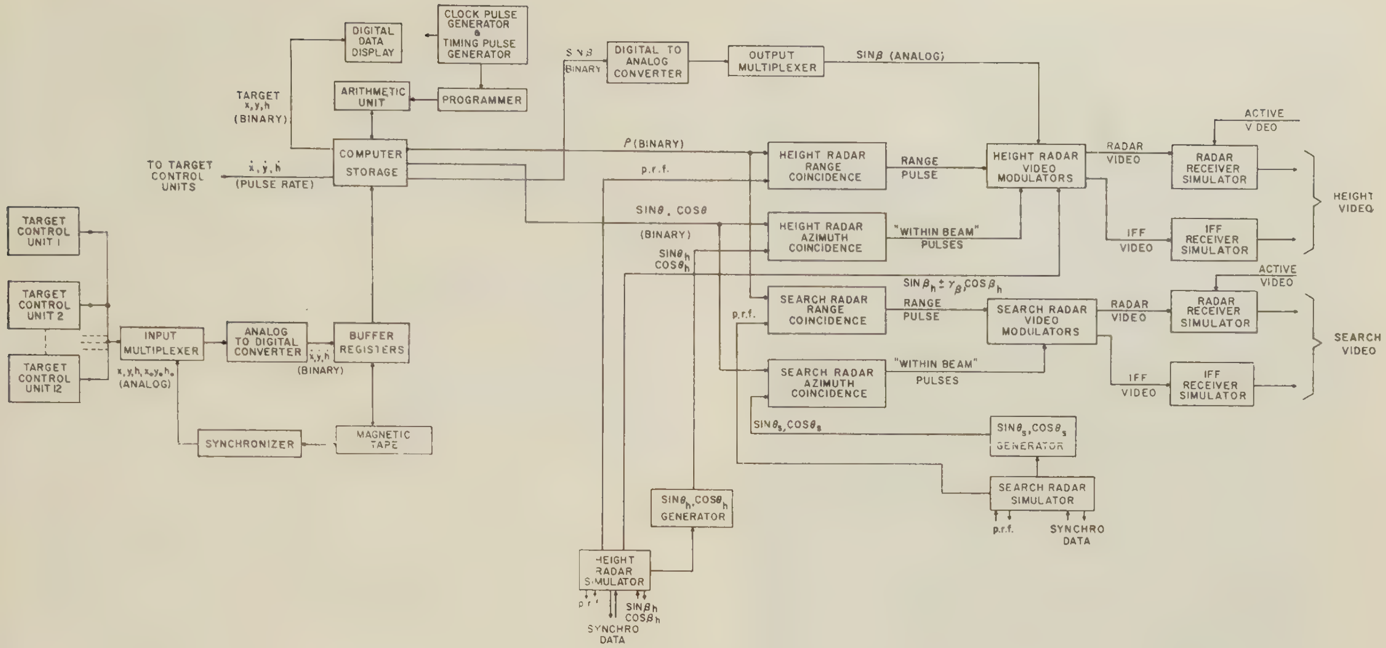


Fig. 1—Block diagram of simulator.

The twenty additional targets are recorded and played back from magnetic tape. These targets are initially recorded by flying a track with one or more of the twelve controllable targets and recording the flight on the tape. Any one or more tracks may be rerecorded on the tape at any time.

Ten raid generators are provided to simulate three additional targets between 1 and 30 miles behind each of the ten prime targets. The spacing between targets is controllable and each of the three iterated targets as well as the prime target is individually controllable by means of a kill switch. Thirty additional targets are therefore provided by this raid capability.

A digital display of the position of any of the 32 targets is continuously available at the main control console. A read-out to an external tape recorder is available upon receipt of a pulse from the external equipment. The information transmitted to the tape recorder is target position in x, y, and h coordinates, target number, and problem time.

A block diagram of the Simulator is shown in Fig. 1. Twelve manually controlled Target Control Units are provided which generate the ground referenced track vectors $\dot{x}$, $\dot{y}$, and $\dot{h}$ as ac analog voltages. The track vectors are suitably modified by the Target Control Unit to take into account speed change with climb or dive, speed change with altitude, rate of climb with altitude, turn rate with altitude, fuel consumption with per cent power and altitude, and air speed indication with altitude. These effects can be modified by replacing a number of plug-in cards to simulate the characteristics of different aircraft.

The outputs of the Target Control Unit are fed to the Input Multiplexer which, in effect, is a thirty-six throw single-pole electronic switch. The timing of the Input Multiplexer is synchronized to the ac analog voltages to enable the peak of the sinusoidal waveform to be sampled and held. This voltage is fed to the Analog-to-Digital Converter which completes each conversion in 320 μsec. The binary numbers generated are fed to buffer registers which supply the information to the Computer Storage at its 1.024 mc bit rate and/or to the Magnetic Tape Programmer at its 1500 cycle bit rate. The Magnetic Tape Programmer feeds its data via the same buffer registers to the Computer Storage. The Synchronizer controls the conversion sequence to eliminate the possibilities of overlap in data transfer from the Analog-to-Digital Converter and the Magnetic Tape Programmer to the Computer Storage.

The Computer Storage consists of ten magnetostrictive delay lines operating at a bit rate of 1.024 mc. Each delay line has a storage capacity of 1024 bits. The Computer Storage stores

$$\dot{x},\ \dot{y},\ \dot{h},\ x,\ y,\ h,\ \dot{\rho},\ \rho,\ \overline{\dot{\sin\theta}} \text{ or } \overline{\dot{\cos\theta}};\ \sin\theta \text{ or } \cos\theta,\ \overline{\dot{\sin\beta}};$$

and sin β for thirty-two aircraft. Intergration is accomplished by adding the speed components $\dot{x}$, $\dot{y}$, etc. to the corresponding numbers x, y, etc. exactly 1000 times each second. A fixed program computer computes to sixteen bit precision ρ, sin θ or cos θ, and sin β at a rate of 7.76 times per second per aircraft. The rates of change of these computed numbers are also determined to permit the interpolation of these values every millisecond. The outputs available from the Computer Storage consist of the aircraft position coordinates x, y, and h, and ρ, sin θ or cos θ, and sin β.

The binary numbers representing sin β are fed to a Digital-to-Analog Converter and Output Multiplexer which supplies dc voltages proportional to each sin β to the Height Video Modulators. The binary numbers

representing ρ, and sin θ or cos θ are fed to the digital range and azimuth coincidence circuitry.

The sin θ is used to obtain coincidence with sin θ_s (θ_s is the Search Radar Azimuth) and sin θ_h (θ_h is the Height Radar Azimuth) when the aircraft bearing angle is between $-45°$ and $+45°$, and 135° and 225°. The cos θ is used to obtain coincidence with cos θ_s and cos θ_h when the angle is between $+45°$ and 135° and 225° and 315°. This procedure utilizes the region of maximum slope of the sine and cosine functions and therefore permits greater angular accuracy to be obtained in the coincidence determining circuitry. The radar servo mechanisms can either follow externally-derived synchro data or generate synchro data for external PPI's. Separate search and height radar PRF generators are provided which can be synchronized to externally derived PRF's.

The output of the range coincidence circuitry consists of pulses precisely located at the appropriate range from the radar "main bang." The outputs of the azimuth coincidence circuitry are pulses indicating that the aircraft is being illuminated by the radar. The angular coincidence for elevation is performed in the individual Height Video Modulators.

The receiver simulators supplied realistically simulate the returns from the search radar receiver and the height radar receiver. The receiver simulators mix the appropriate video signals and attenuate these signals as a function of range. Receiver noise is added and composite signals are fed through filters within the 30 mc IF strip. This signal is then detected and fed to external equipment. When actual radar returns are available, the active video modulates a 30 mc carrier and is mixed with the simulated video prior to detection.

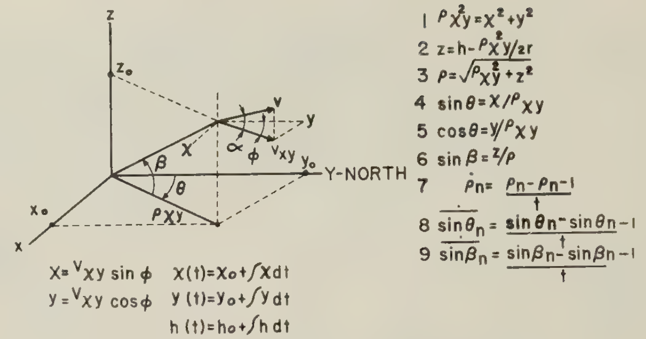
General Considerations

The equations which are solved to simulate a target in three-dimensional space are shown in Fig. 2. The relations between the input parameters, x_0, y_0, h_0, the aircraft speed, V, the aircraft heading angle, ϕ, the rate of climb, $\dot{h}$, and the elevation angle, β, are shown. The $\dot{x}$, $\dot{y}$, and $\dot{h}$ speed components are computed and suitably modified in the Target Control Units to simulate realistically the motion of the aircraft as a function of the per cent power setting, rate of turn, rate of climb, rate of speed increase, and altitude.

The diagram shown in Fig. 3 indicates the relationship between the aircraft and radar parameters necessary to correct for the earth's curvature. The radius of the earth shown in Fig. 3, *i.e.*, $r=4640$ nautical miles, is modified to take into account the slight bending of radar signals. The aircraft velocity V_a is the actual horizontal speed of the aircraft flying at constant height above the earth. The horizontal velocity with respect to the radar datum plane is

$$V_{xy} = V_a \cos \xi.$$

The angle ξ in radians is approximately equal to ρ_{xy}/r which, for ρ_{xy} equal to 300 nautical miles, is 0.0646. Since the cos ξ is 0.998, V_{xy} can be assumed equal to



θ = the bearing angle of target to radar in the horizontal plane.
β = the elevation angle of target to radar in the vertical plane.
$\dot{h}$ = the target rate of climb.
ϕ = the target heading angle.

Fig. 2—Definitions and equations.

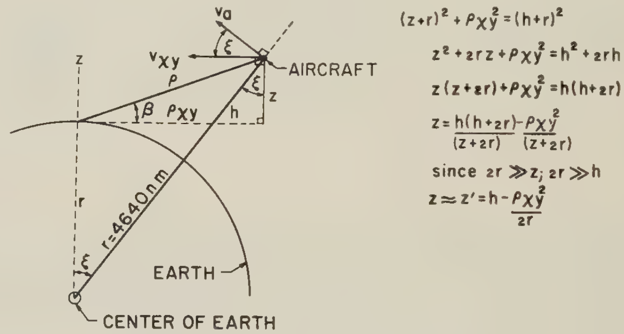


Fig. 3—Earth curvature correction.

V_a. This assumption introduces an error in the aircraft's horizontal velocity component of 0.2 per cent which is negligible since the aircraft's speed is not known to better than 1 per cent.

To obtain the correct elevation angle β, it is necessary to solve the equation, sin $\beta = z/\rho$.

This parameter is obtained by integrating $\dot{h}$ and then obtaining z by the following approximate formula (see Fig. 3):

$$z = h - \frac{\rho_{xy}^2}{2r}.$$

Using this equation, the angle β can be determined to within 0.1 milliradian and z will be accurate to:

$$\pm\ 0.0105 \text{ nm at } \rho_{xy} = 300 \text{ nm}$$

$$\pm\ 0.005 \text{ nm at } \rho_{xy} = 150 \text{ nm.}$$

The analog-to-digital conversion required in the simulator must occur at a sufficiently high rate to eliminate the possibility of large discrepancies in the motion of the aircraft between the continuous analog inputs and the sampled digital outputs. Since the velocity components are sampled, it is necessary to consider the maximum permissible accelerations for straight line and circular paths when determining the discrepancies introduced by the sampling process.

The sampling rate used in the simulator is approximately four per second per aircraft. This means that the aircraft velocity components are exact (to within

the conversion accuracy) every 0.25 second. For a straight line path and a maximum acceleration of 40 knots/sec the aircraft velocity changes 10 knots between sampling intervals. The corresponding position error introduced during the sampling interval is $at^2/2$ or 0.347×10^{-3} nautical mile. If the aircraft is assumed to accelerate from 0 knots to 2000 knots, the cumulative error in position would be $0.347 \times 10^{-3} \times 50 \times 4$ or 0.069 nautical mile. A similar error would be introduced if the actual acceleration were within 0.2 knot/sec of the desired rate set by the operator, or if the acceleration control were moved 0.25 second later. Since the operator cannot move the controls with this accuracy, the slight error introduced will be negligible.

If the aircraft is performing a turn, the $\dot{x}$ and $\dot{y}$ velocity components may vary from zero to V. The maximum rate of turn permissible for an aircraft flying at 2000 knots is approximately 5° per second (8g turn). Since a 90° turn will be completed in 18 seconds, the aircraft average acceleration will be 2000/18 or 110 knots/sec. The cumulative error in position after a 180° turn will not be greater than 0.14 nautical mile. A similar error would be introduced if the actual rate of turn were within 0.05 degree/sec of the dial reading set by the operator, or if the operator set the control 0.25 second later.

Target Control Unit

In order to specify the motion of the manually-controlled target aircraft it is necessary to set in the values for per cent power desired, acceleration, desired altitude, rate of climb or dive, desired heading and rate of turn, as well as the initial position coordinates x_0, y_0, and h_0. In addition, to impart greater realism to the aircraft motion, the manual inputs are modified where applicable by the interdependence of the performance characteristics of the aircraft. For example, the rate of turn, rate of climb, and true air speed are functions of the aircraft altitude as well as the manual control inputs. The function of the aircraft control unit is to provide for the manual inputs, modify these inputs as required and convert these quantities to three-dimensional coordinate analog outputs ($\dot{x}$, $\dot{y}$, $\dot{h}$ and x_0, y_0, h_0).

Fig. 4 shows the front panel of the Target Control Unit. The principal manual inputs are Per Cent Power, Desired Altitude, Rate of Climb, Rate of Dive, Desired Heading, Rate of Turn, and Initial Fuel. In addition, internal adjustments of Rate of Acceleration and Rate of Deceleration are provided. Other panel controls are knobs to set up X_0 and Y_0, Orbit, Video ON-OFF, IFF Mode, Standby-Run-Slave Selector, Computer Speed Range (High, Low) and IAS, TAS, Mach, or Sea Level Mach Selector.

The Target Control Unit outputs are analog voltages representing the horizontal ground speed components $\dot{x}$ and $\dot{y}$, and the rate of change of altitude, $\dot{h}$, if any. The outputs are fed to the multiplexer and the Analog-to-Digital Converter. For initial condition entry, the Initial Conditions button is pushed after setting the X,

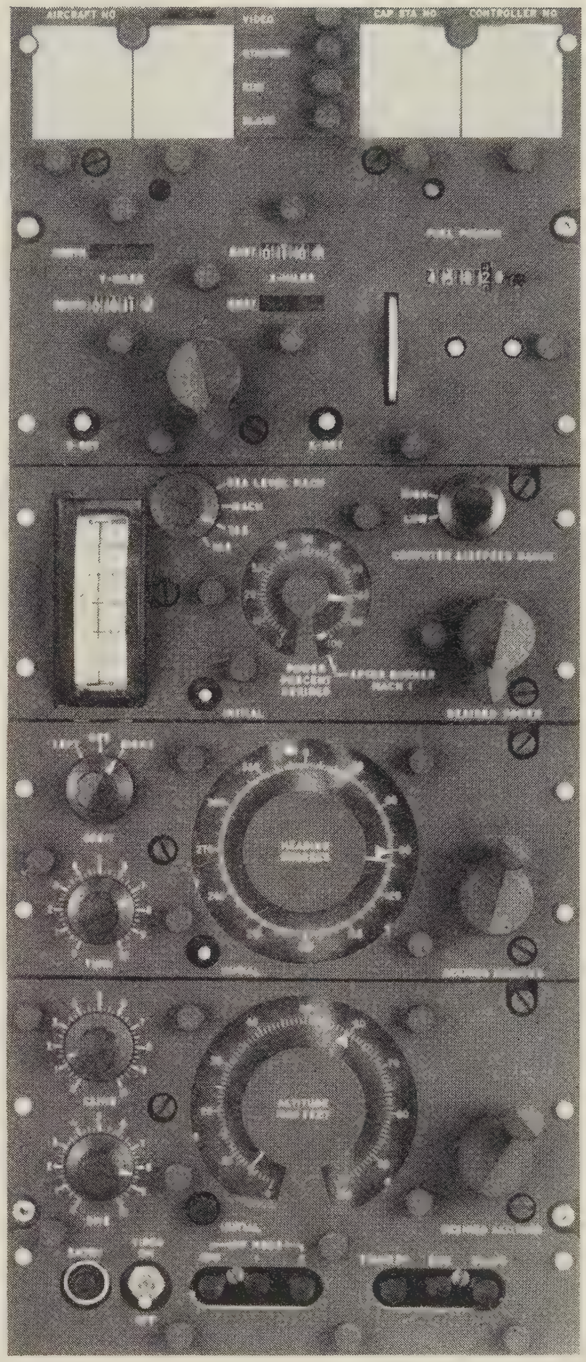


Fig. 4—Target control unit front panel.

Y, and H controls to the desired values. This closes and latches a relay which substitutes x_0, y_0, and h_0 for $\dot{x}$, $\dot{y}$, and $\dot{h}$. When the entry is completed (within 0.25 second) this relay is released by the converter section.

The voltages for $\dot{x}$ and $\dot{y}$ are derived by use of the following equations:

$$\dot{x}_a = V_{xy} \sin \phi \quad \text{and} \quad \dot{y}_a = V_{xy} \cos \phi$$

$$\dot{x} = \dot{x}_a + \dot{x}_w \qquad \dot{y} = \dot{y}_a + \dot{y}_w.$$

Where $\dot{x}_a$, $\dot{y}_a$ are the x and y components of true air speed,

V_{xy} is the true air speed,
ϕ is the actual heading,
$\dot{x}_w$, $\dot{y}_w$ are the x, y wind velocity components.

The addition of the wind and air speed vectors is accomplished by feedback summing amplifiers.

The wind vectors $\dot{x}_w$ and $\dot{y}_w$ are supplied from a central wind generator. The Wind Speed (V_w) Control sets the level of an ac input voltage to a resolver and the Wind Direction Control (ϕ_w) positions the resolver to the desired angle with the resulting outputs:

$$\dot{x}_w = V_w \sin \phi_w \quad \text{and} \quad \dot{y}_w = V_w \cos \phi_w.$$

The true air speed vectors $\dot{x}_a$ and $\dot{y}_a$ are similarly derived from the true air speed through a resolver coupled to the Actual Heading shaft (ϕ_a). The resolvers used have a maximum error of less than 0.1 per cent of maximum output. This error in the relative values of $\dot{x}$ and $\dot{y}$ produces an equivalent error in the value of ϕ_a of approximately 2 milliradians as compared to a desired heading. Since the desired heading is graduated in increments of 2° or approximately 35 milliradians, the resolver error is negligible, particularly since the repeatability error will be a small fraction of the static error.

The Airspeed-Mach Indicator is a dc meter with the dial calibrated in knots and Mach number. A four-position switch selects either TAS, IAS, Mach, or Sea Level Mach by connecting the meter input to the V_{xy} resolver stator, the IAS potentiometer, the Mach potentiometer, or a voltage divider from the V_{xy} resolver. The IAS and Mach potentiometers are connected to the altitude shaft and provide the necessary function modification with altitude.

The V_{xy} voltage input to the resolver driver is a function of the Per Cent Power Desired Setting, the altitude, and the rate of climb (during climb). Sufficient realism is obtained by making V_{xy} the product of three functions, each of one variable, rather than a complex function of three variables; *i.e.*, $V_{xy}=f_1(\rho)\times f_2(h)\times f_3(\dot{h})$, rather than $V_{xy}=F(\rho, h, \dot{h})$. The former case is assumed because it results in much simpler implementation with adequate realism.

The desired functions $f_1(\rho)$, $f_2(h)$, etc. are generated by potentiometers. The functions required are, in general, nonlinear and must be changed when different aircraft types are desired. In order to provide these features, linear-tapped potentiometers with shunts across the tapped sections are used to provide a piecewise linear approximation of the required characteristics. The changes necessary to simulate different aircraft are effected by making the shunting resistors plug-in assemblies.

To obtain the modification of horizontal airspeed with rate of climb, two potentiometers are used, one coupled to the rate of climb shaft; the other to the actual altitude shaft. The first potentiometer reduces the horizontal velocity as the climb rate is increased; the second decreases the reduction factor of the first as altitude is increased, since, in general, climb rate decreases with altitude. Both potentiometers have plug-in shunts to obtain the required approximation of horizontal speed modification with climb rate. A relay, controlled by the altitude mechanism, switches the resolver driver input to the potentiometer output (*i.e.*, V_{xy} modified by climb rate) during climb and back to the potentiometer input during horizontal flight or dive.

The per cent power shaft is positioned manually during the initial conditions set up and by a velocity servo during flight. The manual control input, designated Per Cent Power Desired, is then set in and the control pushed forward. During flight, a change in the desired power setting causes the servo to turn in the required direction until the actual power shaft position is equal to the desired power setting. The follow-up shaft position is indicated internally.

The Fuel Remaining Indicator is an odometer driven by a stepping motor. The odometer is manually set to the desired initial fuel load during the initial conditions set up. During flight, the odometer countdown rate is proportional to the pulse rate, which in turn is a function of the per cent power and the altitude. Plug-in scale factor adjustments make the fuel consumption consistent with the aircraft performance.

The values of x, y, and h are presented on plus-minus odometers or on a dial indicator. The initial values are set in manually by positioning the odometers and dial, which also set up potentiometers to obtain analog x_0, y_0, and h_0 voltages. During flight, the x and y odometers and the altitude dial are driven by stepping motors. The pulse rates and signs for $\dot{x}$, $\dot{y}$, and $\dot{h}$ are obtained from the digital track generator.

Digital Track Generator

The inputs to the computer consist of ten bit binary numbers representing, initially, the x, y, and h positions of twelve "active aircraft" (aircraft 1 to 12) and twenty "programmed aircraft" (aircraft 13 to 32), and subsequently the $\dot{x}$, $\dot{y}$, and $\dot{h}$ velocity components of these aircraft. The "active aircraft" inputs are obtained via the Input Multiplexer, Analog-to-Digital Converter, and the Buffer Registers while the "programmed aircraft" inputs are obtained via the Magnetic Tape Programmer and Buffer Registers.

The Magnetic Tape Programmer uses a six-channel magnetic tape recorder for the digital storage. Channels 1, 2, and 3 of the tape contain the x_0, y_0, and h_0 position information for twenty aircraft in the first twenty-word storage spaces. Subsequent storage spaces contain the $\dot{x}$, $\dot{y}$, and $\dot{h}$ velocity components stored in the same channels. Channel 6 contains clock pulses which are obtained from a crystal-controlled oscillator during the first write operation.

Channel 4 contains the word pulses which mark the start of a new word every 15 clock pulses. Each word consists of eleven information spaces, a parity bit and three blank spaces. The blank spaces are necessary to permit the transfer of information from the Buffer Registers to Computer Storage. Channel 5 contains pulses indicating that information in Channels 1, 2, and 3 is x_0, y_0, and h_0, rather than $\dot{x}$, $\dot{y}$, and $\dot{h}$. Pulse pairs in this channel will be present only during the initial read-in of information at the start of a problem.

The method of coding used provides redundant bits and check bits on the tape to prevent possible errors caused by dropped bits on the tape. Tracks 1 and 2 ($\dot{x}$ and $\dot{y}$) have eleven information pulse spaces, nine for magnitude, one for sign, and one for high or low speed range. The twelfth bit is a parity check bit. Track 3 ($\dot{h}$) has ten information pulse spaces, nine for magnitude and one for sign. The eleventh bit is the parity check bit. Track 6, the clock pulse track, is checked against a normally free running phantastron circuit. If the clock pulse is present, it synchronizes the phantastron. If a pulse is missing, the phantastron generates a pulse very shortly after the time the normal clock pulse would occur. This is used to provide synchronization for the tape at that point. Tracks 4 and 5 use redundant digits to provide checking information; *i.e.*, two successive pulses must be present for each information bit.

Automatic checking equipment is provided to perform the above checks and to indicate the number of errors on a counter. If an error is detected in $\dot{x}$, $\dot{y}$, or $\dot{h}$, the particular component is not read into the computer memory, thus allowing the previous value to remain. The tape will not be stopped since an error in reading will cause an aircraft to fly, at worst, a path slightly in error for only 0.25 second (new information is read four times a second).

The magnetic tape speed is precisely controlled and runs continuously during a simulation run at 7.5 inches per second. This provides a track time capability, using a 2500-foot tape reel, of 1.1 hours. To provide tape for stopping and starting during a problem, a space equal to four words is left blank between each set of twenty aircraft words. This blank corresponds to 40 msec thus providing ample time to start and stop the tape motion.

The analog conversion timing is controlled by the 500-cycle-per-second carrier frequency used in the Target Control Units. A pulse initiates the timing cycle by calling for a conversion of $\dot{x}$, $\dot{y}$, and $\dot{h}$ from an active aircraft. After a variable delay of 0 to 2 msec (1 cycle of a 500 cps signal) a pulse activates the appropriate $\dot{x}$ Input Multiplexer gate. At the same time, a sampling pulse 500 μsec wide activates a "hold" circuit. The sampling pulse terminates at the peak of the $\dot{x}$ wave and this value is held for the analog-to-digital conversion. Three hundred and twenty μsec after the start conversion pulse is generated, the analog-to-digital conversion is complete and the binary number representing $\dot{x}$ is stored in the eleven bit $\dot{x}$ Buffer Register.

The $\dot{y}$ and $\dot{h}$ velocity components are then sampled and converted in a similar manner. The $\dot{y}$ voltage is 180° out of phase with the $\dot{x}$ voltage and $\dot{h}$ is 180° out of phase with $\dot{y}$. The conversion of $\dot{x}$, $\dot{y}$, and $\dot{h}$ is therefore completed about 2.5 msec after the cycle was initiated. At this instant, the ten bit binary numbers which represent $\dot{x}$, $\dot{y}$, and $\dot{h}$ are stored in the first ten bits of three-eleven bit Buffer Registers. The information contained in the Buffer Register is then read out by a high-speed diode matrix in synchronism with the 1.024 mc computer clock pulses.

The $\dot{x}$, $\dot{y}$, and $\dot{h}$ words from the tape are read into a second set of buffer registers in the 8 msec following the start conversion pulse. After the parity check bit has been read, the words are ready to be transferred to Computer Storage in the following 1010 μsec. The complete cycle takes 10 milliseconds and is now ready to repeat.

The $\dot{x}$, $\dot{y}$, $\dot{h}$ inputs for the thirty-two aircraft tracks simulated are stored in magnetostrictive delay lines having a storage bit rate of 1.024 mc. The delay lines also store the initial position of the track—namely, x_0, y_0, and h_0, and the computed information—namely,

$$\rho, \sin\theta, \overline{\dot{\sin\theta}}, \sin\beta, \text{ and } \overline{\dot{\sin\beta}}.$$

The position of these binary numbers within the Computer Storage is shown in Fig. 5.

The binary number representing $x_1, x_2, x_3, \cdots, X_{32}$ is stored in Delay Line 1. The x_1 number is placed in the W_1 storage position, x_2 in the W_2 storage position, etc. The first bit in synchronism with W_1 indicates the sign of x_1 and the most significant bit is in slot 31. Initially, x_0 is entered as a nine bit binary number plus sign. The sign bit is entered in slot 32 and the nine bit magnitude is entered in slots 22–31. Twenty-nine bits are available for the integration process which requires the accumulation of $\dot{x}\tau$ where τ is the integration quadrature interval. The quadrature interval is equal to the delay line circulating time, which is 1000 μsec.

Since the scale factor chosen for the binary numbers is arbitrary, a simple relationship between the binary numbers and nautical miles has been assumed. The 2° number, that is, the first binary bit to the left of the decimal point, is given a weight of 1 nautical mile. Nine bits are carried to the left of the decimal point, permitting a maximum of 511 nautical miles. Since twenty-nine bits are carried in the Computer Storage, the minimum integrated value possible per 1000 μsec is 0.000000953 nautical mile. Therefore, the speed quantization is $0.953\times10^{-6}/10^{-3}$ nautical miles per second or 3.43 knots if the $\dot{x}$ and x numbers are placed in storage as shown in Fig. 5. The maximum $\dot{x}$ attainable is equal to 511 times 3.43 or 1754 knots, since only nine bits are carried. When the $\dot{x}$ number is shifted one place to the left by the control on the Target Control Unit, the $\dot{x}$ quantization is 6.87 knots and the maximum permissible speed is 3509 knots.

The h binary number stored in Delay Line 8 is carried to twenty-six bits and the least significant bit associated with $\dot{h}$ is placed in slot 3. The quantization is 3.43/2 or 1.716 knots in $\dot{h}$ and the maximum $\dot{h}$ is 1754/2 or 877 knots. This corresponds to a quantization of 173.9 feet per minute and a maximum rate of climb or dive of 88,843 feet per minute.

The method used to integrate

$$\dot{x}, \dot{y}, \dot{h}, \bar{\rho}, \overline{\dot{\sin\theta}}, \text{ and } \overline{\dot{\sin\theta}}$$

is shown in Fig. 6. The circulation of the $\dot{x}$ and x binary number is timed so that the least significant bits are fed

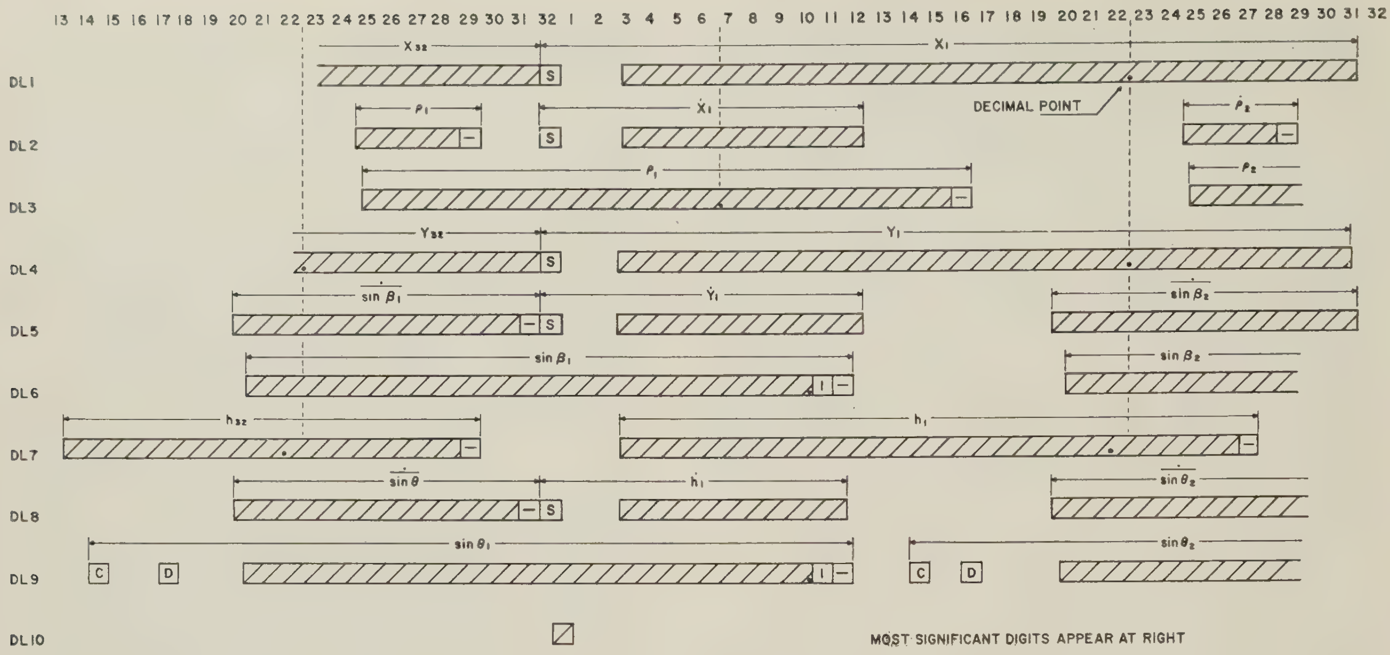


Fig. 5—Computer storage.

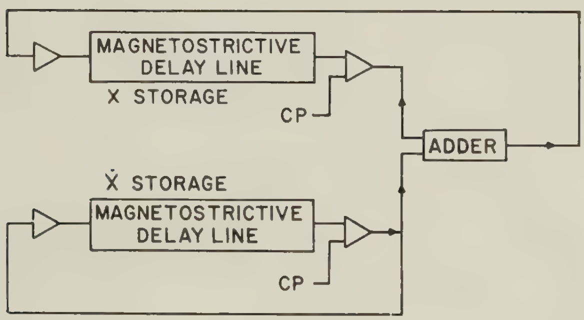


Fig. 6—Integrator.

into the adder-subtractor simultaneously. The $\dot{x}$ value is added or subtracted from x, depending on the sign of $\dot{x}$ and the new x value reenters its delay line.

The Programmer for the arithmetic units controls the transfer of information between the computer storage, the one word registers, the multiplier, the square rooter, the divider, and the various adder-subtractor units. The computation time required to complete the various operations performed is about 16 μsec for adding and subtracting, 280 μsec for multiplication, and 500 μsec for the division and square-root operation.

A computation cycle per aircraft is completed in 129 word times or about 4.031 msec. Since thirty-two computation cycles are required, the computer will redetermine new information for each aircraft in 4.031×32 or 129 msec. This corresponds to a computation rate per aircraft of approximately 7.76 computations per second.

Logic is built into the system to check the recirculation time of the magnetostrictive delay lines and the basic timing circuits of the complete computer. If a random error occurs in the word time generator or the delay line position marker sections of the computer but not in the magnetostrictive delay lines, the logic will both detect and correct the error. If the error occurs in the magnetostrictive line, the error will be detected only.

Video Generation

The $\sin\theta$ or $\cos\theta$ number and the ρ number are fed to the azimuth and range coincidence circuitry, respectively, from storage. These are sixteen bit serial binary numbers available on two input lines at the 1.024 mc computer clock rate. The data for all thirty-two aircraft is repeated every millisecond.

The $\sin\beta$ number is converted into analog form and fed via a multiplexer to each of the thirty-two Height Video Modulators where coincidence with the height radar's elevation angle is determined.

Search radar video is generated when coincidence between $\sin\theta$ or $\cos\theta$ and $\sin\theta_s$ or $\cos\theta_s$ exists. When this occurs, a range pulse is generated by the search range coincidence circuitry and is gated through the search radar video modulator. Height radar video is generated when coincidence between $\sin\theta$ or $\cos\theta$ and $\sin\theta_h$ or $\cos\theta_h$ exists in addition to the coincidence between $\sin\beta$ and $\sin\beta_h$.

The first bit of the $\sin\theta$ or $\cos\theta$ number indicates whether the following word is $\sin\theta$ or $\cos\theta$, the second bit contains sign information, and the most significant sixteen bits of the remaining word are used for the coincidence. The method used to indicate azimuth coincidence permits pulses to be generated every millisecond when the aircraft is within the beam and no pulses when it is not within the horizontal beam.

The search antenna horizontal angle is θ_s and the horizontal beamwidth is $2\gamma_s$. The condition necessary for coincidence is:

$$\sin(\theta_s + \gamma_s) \geq \sin\theta \geq \sin(\theta_s - \gamma_s).$$

Expanding this equation,

$$\sin\theta_s\cos\gamma_s+\cos\theta_s\sin\gamma_s \geq \sin\theta \geq \sin\theta_s\cos\gamma_s-\cos\theta_s\sin\gamma_s,$$

or

$$\cos\theta_s\sin\gamma_s \geq \sin\theta-\sin\theta_s\cos\gamma_s \geq -\cos\theta_s\sin\gamma_s,$$

or

$$|\sin\theta-\sin\theta_s\cos\gamma_s| \leq |\cos\theta_s\sin\gamma_s|.$$

Since γ_s is a relatively small angle, the $\sin\gamma_s \approx \gamma_s$ and $\cos\gamma_s \approx 1$. Therefore,

$$|\sin\theta-\sin\theta_s| \leq |\gamma_s\cos\theta_s|.$$

Similarly, for the cosine comparison

$$|\cos\theta-\cos\theta_s| \leq |\gamma_s\sin\theta_s|.$$

It is relatively simple to implement these equations. The $\sin\theta$ or $\cos\theta$ held in Computer Storage for each of the 32 targets is available every millisecond. The search radar antenna servo supplies $\Delta\theta_s$ pulses to the $\sin\theta_s$, $\cos\theta_s$ generator. When $\sin\theta$ is available from computer storage, $\sin\theta_s$ is subtracted from $\sin\theta$, and the magnitude of the result is compared to $\gamma_s\cos\theta_s$. If the condition $|\sin\theta-\sin\theta_s| \leq |\gamma_s\cos\theta_s|$ is satisfied, a central digital comparator will generate a pulse. The output multiplexer switches the digital comparator output to the appropriate Search Video Modulator in synchronism with the magnetostrictive delay line word circulation. The generation of "within beam" pulses for the height antenna is similar.

The sine and cosine of the height antenna elevation angle is generated in analog form. The vertical beamwidth, $2\gamma\beta$, is multiplied by $\cos\beta_h$. This product, $2\gamma\beta\cos\beta_h$, is modulated by a 50 kc square wave and is then added to $\sin\beta_h$ in a chopper stabilized feedback amplifier. The voltage representing $\sin\beta_h \pm \gamma\beta\cos\beta_h$ is fed to all the Height Video Modulators. In addition, a pulse generated in coincidence with the negative going portion of the square wave is fed to the modulators for control purposes. The analog $\sin\beta$ information for the aircraft is fed to a storage condenser which holds the information while the multiplexer is supplying information to the other Height Video Modulators. $\sin\beta$ is fed to the grid of a high gain difference amplifier. The second input to the amplifier is $\sin\beta_h \pm \gamma\beta\cos\beta_h$. When $|\sin\beta-\sin\beta_h| \leq |\gamma\beta\cos\beta_h|$, the difference amplifier is within its operating range and amplifies the square wave. This waveform is differentiated, and the resulting pulse indicates coincidence between the target and the antenna's vertical beam. "Within beam" pulses for the vertical angle are thereby generated.

The sine and cosine functions needed in the digital azimuth beam comparison must be generated continuously in synchronism with the radar antenna rotation. The method of generating the sine and cosine of the next angular increment of rotation is based on the equations,

$$\sin(\theta+\Delta)=\cos\Delta\sin\theta+\sin\Delta\cos\theta \tag{1}$$

$$\cos(\theta+\Delta)=\cos\Delta\cos\theta-\sin\Delta\sin\theta. \tag{2}$$

For small angles, these may be approximated by

$$\sin(\theta+\Delta)\approx\sin\theta+\Delta\cos\theta \tag{3}$$

$$\cos(\theta+\Delta)\approx\cos\theta-\Delta\sin\theta. \tag{4}$$

If Δ is the increment in the angle, the functions may be generated by implementing (3) and (4). Since the computations are to be implemented in binary form, Δ is chosen as a binary power of one radian. With Δ equal to 2^{-11} radians, there are 12,867.96 intervals in one revolution, which more than satisfies the angular accuracy requirement. Eqs. (3) and (4) now reduce to

$$\sin(\theta+\Delta)\approx\sin\theta+\frac{1}{2^{11}}\cos\theta \tag{5}$$

$$\cos(\theta+\Delta)\approx\cos\theta-\frac{1}{2^{11}}\sin\theta. \tag{6}$$

Eqs. (5) and (6) may be implemented using digital differential analyzer techniques. Since multiplication by a power of 2 is simply a shift in the binary system, only an adder and register are needed to generate each function. The same dynamic circuit elements which are used in the rest of the equipment are used to implement these equations and the sine and cosine are continuously available in serial form.

The Δ pulses are generated by a perforated disk mounted on a 96 speed antenna shaft. There are 134 holes around the circumference of this wheel giving a total of 12,864 pulses per revolution. Since there should be 12,867.96 pulses per revolution, a cumulative error of one pulse in 90° will result. However, this is within the accuracy requirements. The sine and cosine are reset to their true value every quadrant, thus preventing an accumulation of the error.

Sixteen bit binary numbers representing range are available from Computer Storage for each aircraft every millisecond. A conceptually simple procedure for converting this binary number to a video pulse delayed with respect to the radar "main bang" would be to transfer this serial binary number to a sixteen bit register during the radar sweep dead time and to count backwards at approximately an 8 mc rate after receiving the zero range pulse. When the counter reaches zero, a pulse would be generated and would be the video range pulse for the particular aircraft and radar. If two radars and thirty-two aircraft video were required, 64 sixteen bit registers would be necessary. This approach, although conceptually simple, requires an inordinate amount of equipment.

In an attempt to reduce the equipment complexity and still retain the required precision, a method which separates the range number into two parts is used. The least significant 8 bits of the number are converted to analog form and fed via a multiplexer to local target equipment.

The eight most significant bits of the range number are switched to the appropriate target coarse range register via a digital multiplexer. This part of the range number is compared to a central digital range number by 32 local digital comparators for the search and for the height radars.

The central range counter for the search radar consists of a dynamic circulating counter having a count input for each two miles of range after the radar "main bang." Since 8 bits are carried here and also in the 32 local coarse range registers, a digital comparison may be made every 8 μsec. The time interval corresponding to a two-mile round trip range is about 24.7 μsec. Three or more comparisons can therefore be made with the same number in the central counter.

The central counter is started one interval ahead of the actual range. This allows the coarse range comparison to occur one "two-mile interval" before the actual video is to be generated. The coarse comparison pulse for each target closes a gate which allows the next central analog sweep voltage to be compared with the analog voltage for the least significant 8 digits of the local range number. The output of each comparator circuit is the video pulse for the particular target.

The height radar section is the same as the search radar section. The local digital coarse range and the local analog fine range storage do not have to be repeated, however. The only additional equipment for this radar is a central height counter, local digital comparator units, and the local analog comparator circuits.

The Video Modulators accept range pulses from the range coincidence circuits and allow these pulses to enter the receiver simulators when the angle coincidence circuitry indicates that the simulated aircraft is being illuminated by the appropriate radar. The Video Modulator provides video at the appropriate width and generates additional signals such as IFF identification and video iteration (Raid) as desired. The video outputs of these units are in the form of a 17-mc pulse modulated signal.

To duplicate the statistical characteristics of aircraft radar scintillation, it is necessary to produce a voltage possessing a Rayleigh amplitude probability distribution and the appropriate power spectrum. This is done by passing wide-band Gaussian noise through a narrow band-pass filter possessing the correct frequency characteristic. The envelope of the filter output has a Rayleigh amplitude probability distribution. The fluctuation rate of the envelope is determined by the frequency characteristic of the narrow-band filter; adjusting the filter bandwidth permits the spectrum of most targets of interest to be obtained. A variable band-pass filter tuned to approximately 4 kc with a bandwidth of ± 3.0 to 10 cycles is used.

The wide-band Gaussian noise fed to the filter is obtained from a 6D4 thyratron in a magnetic field. In order to permit precise setting of the equipment, the rms noise level of the thyratron is regulated to within 1 per cent by feedback. The envelope of the detected wide-band Gaussian noise has the required Rayleigh distribution.

The beam pattern voltage is produced by a photoelectric function generator. It consists of a cathode ray tube over whose face a template, cut to the shape of the round trip antenna pattern, is mounted and in front of which is placed a photoelectric cell. The cathode ray tube deflection voltages are arranged so that the width of the rectangular pulse generated in the photoelectric cell is proportional to the amplitude of the beam pattern. Each time the antenna scan reaches an azimuth one-half the beamwidth ahead of the target bearing angle, the horizontal sweep of the function generator is triggered, producing this width modulated waveform. A Tachometer, driven by the antenna servo in the central equipment, provides a dc signal proportional to ω, which controls the horizontal deflection rate. Any antenna pattern can be produced merely by obtaining the proper template.

The voltage having a Rayleigh propability distribution is multiplied by the round trip antenna pattern. This is accomplished by amplitude modulating the envelope of the rectangular wave whose width is proportional to the beam pattern. A low-pass filter eliminates the high frequency components and the resulting waveform is proportional to the scintillation noise multiplied by the beam pattern. The output of the multiplier modulates the video pulse. The resultant 17 mc waveform is fed to central equipment where all aircraft video are mixed, receiver noise is introduced, and the composite video is detected.

Equipment Composition

The equipment consists of one Program Control Console which houses the tape recorder storing the 20 target tracks and all the central controls for these tracks. A master video switch and a master-run standby switch is provided so that the complete system may be turned on or off from this one location. The digital display as well as the operating controls for the two-coordinate and three-coordinate radars are also located at this console.

Three Target Control Consoles are provided, each of which contains four Target Control Units. The digital track generator as well as the coordinate conversion, azimuth coincidence, and range generation equipment occupy five racks. The two antenna servos, the input and output analog-to-digital and digital-to-analog units, and the remaining noise and RF equipment occupy another five racks. Most of the system power is distributed by means of one power rack with regulator units located in various sections of the equipment, which has been constructed to meet JAN requirements.

Acknowledgment

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Contributors

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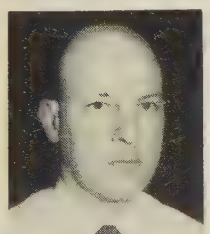
Before joining the Engineering Research and Development Department of the U. S. Naval Training Device Center, where he has been since 1952, he was engaged in the design and development of aircraft systems, components, instrumentation, and structures. While employed by private industry, he accomplished engineering development of training device equipment in the field of electrical and mechanical computers and the application of servomechanisms. At the U. S. Naval Training Device Center, he has served as project engineer on the development of aircraft instrumentation, integral lighting systems, specialized simulators, and research tools and trainers in the aeromedical and aviation training fields. He currently heads the Air Applications Branch of the Engineering Department.

Mr. Achilich is a member of the Engineers and Scientists Association of the Center and the Institute of Environmental Engineers.

Morris Ackerman was born in Washington, D. C., on May 23, 1922. He received the Bachelor of Aeronautical Engineering (BAE) degree from the Catholic University of America, Washington, D. C., in 1943.



M. Ackerman

From 1943–1944 he worked as engineer with the Ryan Aeronautical Company. He was concerned with flight test engineering, developing the photo panel recorder for XFR-1 aircraft test flight and the landing gear drop test recorder. When with the U. S. Navy from 1944–1946, his work covered electronics, theory and maintenance of airborne, radar, and communications equipment. In 1946–1948 he was a designer at David Taylor Model Basin, where he worked on wind tunnel models for aircraft and missiles and developed related test equipment. Since 1949 he has been associated with Nuclear Products-Erco Division of ACF Industries, Inc. He has been responsible for the design of instruments and cockpits for F9F-2, F9F-5 flight simulators, and eventually all phases of these flight simulator contracts. He is in charge of administrative and technical supervision of engineering groups for the Erco plant's entire product engineering effort.

Mr. Ackerman is a member of the Institute of Aeronautical Sciences.

Maurice D. Bennett was born on July 11, 1904, in Windsor, N. Y. He received the B.S. degree at Pratt Institute, Brooklyn, N. Y., 1927, and has attended Syracuse University, N. Y., and Union College, Schenectady, N. Y.

M. D. Bennett

He was associated for over twenty years with the Yale and Towne Manufacturing Company, where he became assistant director of engineering and research, and during World War II supervised the design and manufacture of radar components including waveguides, rotating joints, crystal mixers, antenna systems for the S-, X-, and K-band. He was also in charge of electrically-operated bank vault protective devices and similar electrical and electronic equipment.

For the past ten years he has been in charge of engineering activities of The Reflectone Corporation, Stamford, Conn., where he is presently vice-president of engineering. He has initiated and supervised the design, development, and installation of many military devices such as radar and sonar trainers, fleet tactics and crew trainers, and many other devices of this type. He possesses several patents in the field of mechanical control instruments.

Mr. Bennett is a registered professional engineer of the State of Connecticut and a member of the Optical Society of America.

Eugene W. Cairns was born on January 18, 1928, in Baldwin, N. Y. He received the B.S. degree in aeronautical engineering from Rensselaer Polytechnic Institute, Troy, N. Y., in 1953.

E. W. Cairns

Upon graduation he was employed by Grumman Aircraft Engineering Corporation as an internal flow and propulsion aerodynamicist, engaging in the preparation of new aircraft powerplant performance, ejector design, and full-scale testing and design of turbo-jet engine inlet ducts. In 1956, he joined the Fighter-Helicopter Branch of the Operational Flight Trainer Division at the U. S. Naval Training Device Center, Port Washington, N. Y., and at present is senior project engineer on the H-37A Helicopter Operational Flight Trainer and the F3H-2 Weapon System Trainer.

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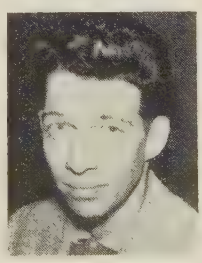
S. Domeshek was born in New York, N. Y., in December, 1920. He received the B.S. degree in geology and chemistry from the College of the City of New York, in 1940, and mechanical engineering from New York University, in 1956.

S. Domeshek

During World War II he served as a navigator and combat information officer aboard a destroyer in the Pacific. He is presently with the U. S. Naval Training Device Center at Port Washington, N. Y., as head of the Visual Systems Branch. His work at the Center has covered organization and direction of development of mapping and navigation systems and the engineering development and application of terrain models. He has also developed areas in the engineering applications of optics including orthogonal optical projection, variable magnification optical surfaces, and optical radar simulation. He has been awarded a number of patents in these areaas of work.

Mr. Domeshek is a member of the National Society of Professional Engineers, the American Society of Photogrammetry, and the ASME. He is a registered professional engineer in New York.

Robert M. Eisenberg (M'57) was born in Edensberg, Pa., on January 14, 1926. He attended U. S. Army Communication School, Fort Benning, Ga., in 1944, and the Commercial Radio Institute, Baltimore, Md., in 1946.



R. M. Eisenberg

He obtained his amateur radio license in 1941. From 1941 to 1943 he was an assistant instructor, working with the National Youth Administration, Adult Vocational Training Program, and the Signal Corps Preradar. In 1943 he joined Herback and Rademan and assisted in the construction and development of Geiger Counters. He also designed and constructed nonradiating beat frequency oscillators. From 1943 to 1944 he served as

engineer and announcer at Radio Station WKOK. In the U. S. Army in 1944 to 1946, he maintained and operated AM and FM receivers and transmitters, designing and supervising the construction of station KOFA AM studio and transmitter facilities in Salzburg, Austria, and the entire WOFA AM facilities at Vienna, Austria. He worked as a serviceman from 1946 to 1952 with Montgomery Ward and Company. Since then he has been associated with Nuclear Products-Erco Division of ACF Industries, Inc., where he is presently senior development engineer. Mr. Eisenberg has been responsible for the design, checkout, and acceptance of the P5M-1 trainer and for all design and systems development for the B-57 simulator.

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W. P. JAMESON

William P. Jameson was born in Washington, D. C. on September 13, 1928. He studied engineering and accounting at the University of Maryland, College Park, from 1947–1951, and the U. S. Army Fire Control School and Radar School in 1951.

In 1946 to 1948 he worked at Maryland Airport as C.A.A. ground instructor in meteorology, navigation, aircraft and engines. From 1951–1953 he was in the U. S. Army Ordnance Corps where he served as instructor in fire control systems, radar, computers, hydraulic power controls, and optics for T-38 and M-33 systems. Since 1953 he has been with Nuclear Products-Erco Division of ACF Industries, Inc., where he is presently senior computer engineer. He has instructed Air Force personnel in trainer theory and maintenance on F9F-5, F9F-6, F86-D, and F86-K simulators.

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M. KAMENETSKY

Max Kamenetsky was born in New York City, N. Y., on July 25, 1927. He received the B.S. degree in electrical engineering from the College of the City of New York in 1950.

After several years of work on shipboard radar systems, he joined the Office of Naval Research, U. S. Naval Training Device Center, Port Washington, N. Y. He is presently a project engineer, involved in the design and development of tactics trainers for aircraft weapons systems.

N. B. MICKELSON

Nils B. Mickelson was born in Brooklyn, N. Y., on December 28, 1910. Concurrent with his studies at Brooklyn Polytechnic Institute, N. Y., he was research assistant at Bell Telephone Laboratories, New York, N. Y., from 1928 to 1933, when he joined the technical staff of Arma Corporation. In his capacity as development engineer, and later as senior development engineer, he was responsible for a wide variety of systems and components in the navigation and ordnance categories, including gyro compasses, gyro stabilization, servo systems, computers and synchros. Since 1937 his efforts largely have been directed toward the electromechanical analog computer and its applications.

In 1951 he was appointed staff engineer at The Reflectone Corporation, Stamford, Conn., and has been engaged in the system design and development of simulators, synthetic training devices, and computers.

Mr. Mickelson is a member of the Optical Society of America and president of the Fairfield County Astronomical Society.

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L. PACKER

Leroy Packer (S'48-A'51–M'56) was born in New York, N. Y., in 1923. He received the B.S. degree from Columbia University, N. Y., in electrical engineering in 1947, and the M.S. degree from the Moore School of the University of Pennsylvania, Philadelphia, in 1950.

From 1948 to 1950, he was a research engineer on the staff of the Franklin Institute Research Laboratories, where he did extensive work on airplane simulators. From 1950 to 1952 he was section leader of the input devices section of the Research Division of the Burroughs Adding Machine Company. At Burroughs he did research on high-speed input devices for large-scale digital computers, and did transistor circuit development. In 1952 he joined the staff of the Columbia University Electronics Research Laboratory, where he was group leader of the Digital Techniques Group. There he directed important research work on navigational and guidance systems and developed digital devices for use in the tracking of military aircraft from radar- and beacon-gathering sources. In 1954 he joined the Polarad Electronics Corporation as head of the General Engineering Department, being responsible for all systems work as well as the supervision of the Circuits Group, Computer Group, and Analysis Group. In 1956 he joined the staff of the General Applied Science Laboratories, Inc., as department manager.

Mr. Packer is a member of Tau Beta Pi.

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M. RAPHAEL

Martin Raphael (S'51–A'53–M'57) was born in New York, N. Y., in 1930. He attended Brooklyn College, N. Y., and the College of the City of New York, receiving the B.S. degree in electrical engineering in 1952. He attended Columbia University, N. Y., and received the M.S. degree in electrical engineering in 1956.

During 1951, he worked for the Republic Aviation Corporation as an engineer in the Design Section. After his graduation in 1952, he joined the Columbia University Electronics Research Laboratory. Here his work included an automatic tracking system for beacon-equipped aircraft, a data-gathering section for a tactical bombing system, and a system for the early detection of ICBM. During a portion of the time he was at Columbia, he was on the staff of the Electrical Engineering Department of C.C.N.Y. He also did consulting work for the Polarad Electronics Corporation, involving system designs for various types of automatic test equipment which required the application of digital and related techniques. He joined the General Applied Science Laboratories, Inc., in 1956. His work has included direction of projects in the computer and digital fields, design of test equipment, and design of various simulation and measuring equipments. He has also programmed some problems for digital computers. He is the author of several papers relating to systems and implementations in the computer field.

Mr. Raphael is a member of Tau Beta Pi and Eta Kappa Nu.

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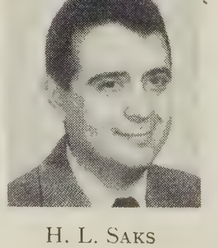

H. L. SAKS

Harold L. Saks was born in April, 1922, in New York, N. Y. He commenced his engineering studies in 1949 at RCA Institutes and completed the Communications Engineering Course in May, 1951. He received the B.S. degree in electrical engineering from the Polytechnic Institute of Brooklyn, N. Y. in 1955.

Following graduation from RCA Institutes, he was employed as a junior engineer by Lavoie Laboratories, where he worked on the development of a UHF signal

generator and a wide-band oscilloscope. In 1952 he was employed by Fada Radio, where he participated in the development of a countermeasures receiver system. In 1953 he joined Freed Electronics and Controls Corporation, where he was responsible for the electronic circuitry of an ultrasonic light modulator for radar display recording. At the beginning of 1955 he was employed by Polarad Electronics Corporation. There he developed front end and IF circuitry for automatic intercept VHF and UHF receivers. He later became project engineer for the development of X-band and UHF receiver heads for a panoramic countermeasures receiver. He joined the General Applied Science Laboratories, Inc. in September, 1956, as a project engineer. At GASL he has been responsible for the development of video, RF, and analog computer circuitry for several radar simulators.

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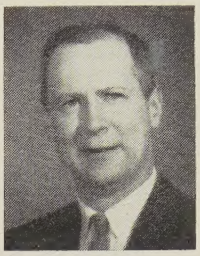
John T. Slattery was born in Brooklyn, N. Y., on November 28, 1915. He received the B.S. and B.M.E. degrees from St. John's University, Brooklyn, N. Y., and the Polytechnic Institute of Brooklyn, respectively, in 1936 and 1954.

During World War II, he attended the U. S. Coast Guard Academy, O.C.S., New London, Conn., and later was radar officer and deck officer with the Destroyer Force of the Atlantic and Pacific Fleets. At present he is a project engineer concerned with the development of landmass simulation systems for weapon systems trainers at the U. S. Naval Training Device Center, Port Washington, N. Y.


J. T. Slattery

Mr. Slattery is a member of Pi Tau Sigma.

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